Tenth International Symposium

Monitoring of Mediterranean Coastal Areas: Problems and Measurement Techniques

Livorno (Italy) 11th - 13th June 2024

edited by
Laura Bonora, Marcantonio Catelani,
Matteo De Vincenzi, Giorgio Matteucci

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MONITORING OF MEDITERRANEAN COASTAL AREAS:
PROBLEMS AND MEASUREMENT TECHNIQUES

ISSN 2975-0288 (ONLINE)

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FIRENZE UNIVERSITY PRESS
2024

Tenth InternationaSymposium Monitoring of Mediterranean Coastal Areas: Problems and Measurement Techniques : Livorno (Italy) 11th-13th June 2024 / edited by Laura Bonora, Marcantonio Catelani, Matteo De Vincenzi, Giorgio Matteucci. – Firenze : Firenze University Press, 2024.
(Monitoring of Mediterranean Coastal Areas: Problems and Measurement Techniques ; 2)

https://books.fupress.com/isbn/9791221505566

ISSN 2975-0288 (online)
ISBN 979-12-215-0556-6 (PDF)
ISBN 979-12-215-0557-3 (XML)
DOI 10.36253/979-12-215-0556-6

Cover graphic design: Alberto Pizarro Fernández, Lettera Meccanica SRLs
Front cover image: *Old Fortress Livorno (Italy): The Canaviglia bastion and the Palace of Francesco I de' Medici*, photo by Gianni Fasano

Edited by: Laura Bonora, Marcantonio Catelani, Matteo De Vincenzi, Giorgio Matteucci
Desktop publishing: Laura Bonora, Matteo De Vincenzi
Graphic Design: Gianni Fasano

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FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

The online digital edition is published in Open Access on www.fupress.com.

Published by Firenze University Press
Firenze University Press
Università degli Studi di Firenze
via Cittadella, 7, 50144 Firenze, Italy
www.fupress.com

This book is printed on acid-free paper
Printed in Italy

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Preface

The tenth edition of the *Symposium Mediterranean Coastal Monitoring: problems and measurement techniques*, held in Livorno from 11th to 13th June 2024, represented a significant goal for the event born in 2006 from an idea of the dr. Fabrizio Benincasa, Research Director of CNR. In its almost twenty-year history, the Symposium has seen the approval and participation of scholars from all over the Mediterranean basin grow over the years. Edition after edition, it has increasingly confirmed itself as an opportunity for dialogue, comparison and constructive debate on new perspectives and challenges in the field of monitoring and conservation of Mediterranean coastal ecosystems and to evaluate strategies and actions for the protection and safeguard of the marine and coastal environment.

This edition of Symposium has been organized by the Institute of BioEconomy (IBE) of the National Council Research (CNR) in collaboration with the Italian Society of Silviculture and Forest Ecology (SISEF). This edition, like those of the last years, is divided into the following Sessions: Flora and fauna of coastal ecosystems: protection, management, monitoring; Geography Tourism and Landscape of the coastal area; Coastal and underwater cultural heritage; Morphology and evolution of coasts and sea beds; Coastal and offshore engineering.

Also in this tenth edition, the Symposium has highlighted the importance of multidisciplinary and interdisciplinary studies, and the consequent need for integrated analysis and investigation approaches. The coastal system is both a complex and fragile natural structure, whose evolution is the result of delicate physical, chemical and biological balances, highly influenced by anthropic actions. Therefore, the Symposium aims to contribute to the dissemination of knowledge on this natural system, providing information on the dynamics and/or variations of marine-coastal ecosystems, hoping to represent a useful contribution to increasing man's respect for the land that hosts him.

The success of this edition is confirmed by the 180 contributions selected by the Scientific Committee from those submitted. The participation covered all the topics foreseen by the sessions, engaging many countries on the Mediterranean coasts. We would also like to highlight how the participation of young researchers, also in this edition, is the confirmation that the Symposium continues to represent an opportunity and an important point of reference for the scientific comparison of ideas and results.

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Special thanks to cpt. Paolo Sottocorona for the introductory keynote on *the Effects of climate change on the Mediterranean Sea*, which was particularly appreciated by the participants.

Finally, we would like to thank our colleagues who have dedicated their time and energy to the success of the Symposium. Likewise, we would like to thank all the participants, who, with their presence, have shown that they believe in our initiative by sharing its scientific objectives.

The Editors

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Presentation of Proceedings

Giorgio Matteucci

As described in the Preface of this Proceedings Volume, the Symposium has been confirmed as the international occasion to present the research carried out in recent years on the monitoring of the Mediterranean Coastal Areas and therefore as a space to present new proposals and promote actions for the protection of the marine and coastal environment.

The interdisciplinary of the Symposium has been the event for consolidating the scientific exchanges of scholars from Mediterranean countries and for promoting a greater diffusion of the research and related results.

It is relevant that the Symposium is considering the Mediterranean Coastal Areas in all their aspects: from morphology and evolution of coastlines and seabeds to the landscape dynamics and integrated protection; from the dynamics and protection of coastal and underwater flora and fauna to cultural heritage, considering the challenges of pollution, energy production, environmental assessment and regulatory context of coastal areas.

In this 10th edition, in fact, we had more than 130 participants from 16 countries; this is a sign of great success and willingness to be presence in Livorno to discuss problems and propose solutions for the Mediterranean coastal areas.

The international scientific committee supervising the Symposium, formed by 42 renowned scientists, did a great and hard work in selecting 44 oral and 110 poster presentations among the 180 contributions received.

For all selected works a *double peer review* has been carried out for the inclusion of the extended papers in this Volume.

Also, for this edition the collaboration between CNR-IBE and Italian Society of Silviculture and Forest Ecology (SISEF) in the organization of the Symposium has been continued.

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The aim of CNR-IBE and SISEF is to continue in their collaboration to organize the next edition, the 11^{th}, of the Symposium and to involve an increasingly wide audience of scholars, supporting in this way the dissemination of scientific results obtained in the field of protection of the Mediterranean coasts.

Giorgio Matteucci
The Director of CNR-IBE
The Vice President of SISEF

Introduction

Marcantonio Catelani

I would like to introduce the presentation of this edition of the *International Symposium on Monitoring of Coastal Areas*, the tenth edition, by recalling the Resolution adopted by the General Assembly of the United Nations on September 2015, where the Sustainable Development Goals (SDGs) are defined in the *Agenda ONU 2030*.

Adopted by all United Nations Member States in 2015, the Agenda represents the world's best plan to build and maintain a better world for people and our planet; to this aim, 17 Goals are defined in terms of targets and scheduled in the time.

The official starting point of the Agenda 2030 and, consequently, the implementation and application of its 17 Sustainable Development Goals, coincided with the beginning of 2016. The aim of the Agenda is to guide the world on the road ahead over the next 15 years, with countries pledging to achieve them – Goals and related targets - by 2030. In the Resolution adopted by the General Assembly of the United Nations held in September 2015 [1] the official document of the Agenda [1], for the environmental sustainability, reported that (cfr.33):

"We recognize (by the Mondial leaders who attended the General Assembly) *that economic and social development depends on the sustainable management of our planet's natural resources. Accordingly, we are determined to preserve and sustainably use seas and oceans, freshwater resources as well as forests, mountains and land; and to protect biodiversity, ecosystems and wildlife. In addition, we are determined to promote sustainable tourism, combat water scarcity and aquatic pollution, enhance cooperation against desertification, sandstorms, environmental degradation, and droughts, and promote resilience to and reduction of the risk of environmental disasters".*

In the context of the environmental sustainability, attention for the topics of the Symposium have to be made for some targets of the Goal 7 – Affordable and clean energy (*Ensure access to affordable, reliable, sustainable and modern energy),*

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Goal 9 - Industry, innovation and infrastructure (*Build resilient infrastructure, promote sustainable industrialization and foster innovation* and Goal 12 – Responsible consumption and production *(Ensure sustainable consumption and production patterns)*. For such targets a correlation with the research activity can be found in many works proposed for the Symposium. However, of particular interest and impact to the content and topic of the Symposium are the Goal 13 – Climate action *(Take urgent action to combat climate change and its impacts)* and especially the Goal 14 – Life below water *(Conserve and sustainably use the oceans, seas and marine resources)*. Goal 14, indeed, is about conserving and sustainably using the oceans, seas and marine resources. Healthy oceans and seas are essential to human existence and life on Earth. The Symposium focuses the attention on the Mediterranean Area but some targets of this Goal, as we can see below, are strictly related with the proposals and the research activities developed by the attendees of the Symposium:

- to prevent and significantly reduce all forms of marine pollution, especially that resulting from activities carried out on land, including pollution of marine debris and nutrients;
- sustainably manage and protect marine and coastal ecosystems to avoid particularly adverse impacts, including by strengthening their resilience, and take action to restore them to healthy and productive oceans;
- minimize and address the effects of ocean acidification, including through increased scientific collaboration at all levels;
- preserve at least 10 % of coastal and marine areas, in accordance with national and international law and based on the most accurate scientific information available;
- increase scientific knowledge, develop research and transmission capacity of marine technology, with the aim of improving water health and increasing the contribution of marine biodiversity.

Consequently, considering that the Sustainable Development Goals and related targets are well defined and clearly described in the *Agenda ONU 2030*, a fundamental question can be asked to the Researchers' Community: how the Community can contribute to the study of such topics? What is the state of the art? What approaches and results? What open tasks and future developments? What time and scheduled programs? And so on.

It is clear that the above targets, as defined for Goal 14, are very broad, differentiated in purpose and, as such, involve different and complementary research expertise. A little contribute for the Agenda 2030 and, in particular, for this Goal, but also for some targets proposed in Goals 7, 9, 12 and 13 that can be assumed as strictly correlated with the coastal monitoring, can be found in the topics and research activities developed and proposed in this *International Symposium on Monitoring of Coastal Areas: Problems and Measurement Techniques.*

The broad scope of the Goal 14, but also the interest of researchers in some topics of the Goals 7, 9, 12 and 13 that are strictly correlated with the monitoring activities of the Mediterranean area, is the main reason of why the Scientific board of the Symposium structured this event, as tradition, in different and specific sessions. This choice allows us to focus the research activity on specific fields of interest.

The Symposium, organized every two years, is proposed as a place to make known the research carried out in recent years on the topics of monitoring the Mediterranean; and therefore, it is an opportunity to present new proposals and promote actions in favor of the safeguard of the marine and coastal environment. The Symposium addresses issues related to Mediterranean coastal areas and investigations in technical and instrumental solutions to face problems related to: energy production in the coastal area, coastal pollution, morphology and evolution of coastlines, flora and fauna of the littoral system, management and integrated coastal protection, coastline geography, maritime and coastal tourism human influence on coastal landscape. In detail, the special sessions, for which we give the name and a brief description, cover:

- *Flora and Fauna of coastal ecosystems (chairs: Davide Travaglini, University of Florence, and Sandro Lanfranco, University of Malta)*
  Coasts are ecotones between sea and land. Coastal ecosystems are highly dynamic, they interact with different land use systems and are often in direct contact with urban environments, where the pressure of human activities on the coast is higher. All these features make up a complex environment so that its flora and fauna show particular morpho-physiological, ecological and behavioral adaptations. The session includes the following topics: flora and fauna of coastal (forests, maquis, beach-dune, wetlands) and marine ecosystems; protection and restoration of coastal ecosystems; sustainable management and efficient use of coastal ecosystems and their ecosystem services; resilience and adaptive capacity of coastal ecosystems to climate change-related hazards; biodiversity conservation and protection of threatened species; methods and new technologies for monitoring flora and fauna of coastal and marine ecosystems.
- *Morphology and evolution of coastlines and seabeds (chair: Giovanni Sarti, University of Pisa).*
  The session includes contributions related to the morphodynamic processes that characterize the various types of coasts: from high to low coasts and from natural to anthropized. Each specific topic, inserted in this context, is pertinent to the session: from the space-time evolution of the coastline, including the retro-coastal dune systems, to the morphodynamics of the submerged beach, as well as analysis of the physical-chemical qualities of the water column. Added to these aspects are techniques for evaluating the sedimentary budget (sedimentary contribution of fluvial-deltaic systems, methods of redistribution of sediment along the coast, offshore sediment loss). The topics of the Session also include the dynamics triggered by anthropic factors, both local (defense works, ports, etc.) and global ones (greenhouse effect, climate change and danger of submerging the coasts), as well as the activities of protection and restoration of coastal areas.
- *Coastal and offshore engineering: energy production and transport, port and offshore structures, water quality, measurements and monitoring, data processing and services, digital twins, economic-environmental assessment, regulatory context (chair: Lorenzo Cappietti, University of Firenze)*
  This session includes the coastal and offshore engineering topics related to:

infrastructures structures devices and techniques for the production of energy that exploit different sources (e.g. waves, currents, tidal range, wind, sun), energy transport infrastructures (e.g. power lines, regasification plants), energy accumulation systems (e.g. compressed-air energy storage, hydrogen, pumped hydro), water desalination plants and techniques, ports and offshore structures, circulation, mixing, marine water quality and pollution (micro and macro plastics, eutrophication, anoxia), sensor systems and instruments for measurements and monitoring, evaluation of the reliability and performance of measurement systems, information and data acquisition systems, digital twins, development of coastal services (e.g. Copernicus downstream services), economic assessments and impact analysis of new energy production plants on local economic systems and climate-changing gas emissions, analyzes of the regulatory context.

- *Geography, Tourism and Landscape of the coastal areas. Enhancement, safeguarding and dynamics of the territory (chair: Donatella Privitera, University of Catania)*
  Coastal areas play a strategic role in the Mediterranean basin, one of the most important centers of biodiversity worldwide, as they fulfill natural, residential, recreational, and commercial functions of particular relevance and ancient tradition. Actually, managing and sustainably protecting marine and coastal ecosystems is more important than ever, along with their conservation and development. Therefore, analyzing and deepening our understanding of the physical, environmental, landscape, tourist, and cultural characteristics and dynamics of the reference territories are considered fundamental. This session focuses on the potential and challenges of geographical, landscape, economic, legislative, and socio-cultural aspects, as well as various forms of human impact and environmental restoration that affect coastal territories, with a specific emphasis on gaining a profound understanding of urban system dynamics and their redefinition in a circular and sustainable manner, including Mediterranean waterfronts. Contributions related to the tourism development of coastal areas, landscape and anthropized areas dynamics, the history, description, and enhancement of landscapes, landscape design, planning, and legislation, especially regarding island territories, fall within this session.
  Other topics of the session include case studies on coastal smart cities, the relationship between the surrounding environment and the network of local resources within cities as super-organisms, the urbanization of coastal areas and the marine ecosystem, sustainability and protected areas in participatory and shared territorial governance.
- *Underwater and Coastal Cultural Heritage (chair: Marinella Pasquinucci, University of Pisa)*
  The session aims to focus on the palaeogeographical, archaeological, topographical, historical and landscape aspects of coastal areas and/or seabeds, in an interdisciplinary perspective, with attention to the settlements and settlement patterns, the archaeology and history of sailing and maritime trade, the structures of ports/ landings, the transmission of cultures and ideas, the landscape context and its evolutionary dynamics, the museum heritage, enhancement and safeguard.

I would like to conclude this brief presentation of the Symposium by recalling the statement of all United Nations Member in 2015, contained in the Agenda 2030: "*We announce today 17 new Sustainable Development Goals with 169 associated targets that are interconnected and indivisible. This is the first time that world leaders have engaged in a common effort and action through such a broad and universal policy agenda. We are moving towards sustainable development, dedicating ourselves to the pursuit of global growth and win-win cooperation that would result in greater gains for all countries and the whole world. We reiterate that all states can, and should, freely exercise total and permanent sovereignty over their wealth, natural resources and economic activities. We will implement the Agenda so that all can reap its benefits, for today's generations and those of the future. In doing so, we reaffirm our commitment to international law and emphasize that the Agenda must be implemented in such a way that it is in line with the rights and duties of states enshrined in international law".*

Research is, by its nature, a dynamic and interdisciplinary activity. The papers presented at the Symposium, whether in oral or poster form, demonstrate the strong interest and active and systematic involvement of many countries, with the common goal of making a contribution, albeit a contained one due to the breadth and complexity of the issues concerning environmental impact, but above all to nurture fruitful moments of discussion. The intent of the Symposium, now in its tenth edition, is therefore and as far as possible, to constitute one of the points of aggregation and reflection on some of the themes of the UN 2030 Agenda.

The Symposiarch
Marcantonio Catelani
Department of Information Engineering
University of Florence

References

[1] Resolution adopted by the General Assembly of the United Nations on Sept. 25, 2015 - https://unric.org/it/wp-content/uploads/sites/3/2019/11/Agenda-2030-Onu-italia.pdf
[2] https://www.un.org/sustainabledevelopment/oceans/
[3] https://asvis.it
[4] https://unric.org/it

Effects of climate change on the Mediterranean Sea

Paolo Sottocorona
Meteorologist – MeteoLA7

But what if all this really was a salvation for the planet?
One fine morning the light bulbs do not turn on,
the refrigerator is off; banks and insurance companies fail;
money is no longer worth anything;
bicycles and clean energy are back in vogue;
it is finally stated: oil wars no longer have any reason to exist.
Imagination?
But if humanity does not come to its senses,
the apocalypse will really come.

Dario Fo, 1997 Nobel Prize in Literature.

The drama of unstoppable global warming does not seem to raise excessive fears and worries among the majority of the planet's population. On the other hand, on the contrary, a certain number of citizens think that the problem is becoming a desperate obsession. Personally, I must admit that I have long been part of this tormented latter category. We don't know if it will be an apocalypse, but the data, and their trends, are certainly not reassuring. Compared to an average global warming of 1.5 °C, a 2.3 °C increase has been estimated for Europe. This is associated with fires, heat or cold waves, melting of Alpine glaciers (with a loss of 5 km^3 of ice), damage to coastal structures (8000 km long for Italy alone).

The Mediterranean Sea, which normally has a temperature 4 °C higher than the Atlantic Ocean, has warmed three times more than other seas, while paradoxically the slowdown of the Gulf Stream[1] could lead to a significant drop in temperatures over the North Atlantic coasts (Great Britain, Scandinavia). The weakening of the Gulf Stream's mitigating effect could bring places on the eastern Atlantic coasts to temperatures close to those of the Canadian Atlantic coasts[2].

Figures 1 and 2, based on the *Copernicus Marine Service* data, show the sea surface temperature (SST) anomalies recorded in June and October 2022 in the Mediterranean Sea. These anomalies were influenced by the heatwaves in Europe that occurred in late spring/early summer and late summer/early autumn 2022. In particular, SST anomalies in certain areas of the Mediterranean Sea peaked at +5 °C above historical average values, such as the areas off the coasts of north-western Italy and south-eastern France and Spain.

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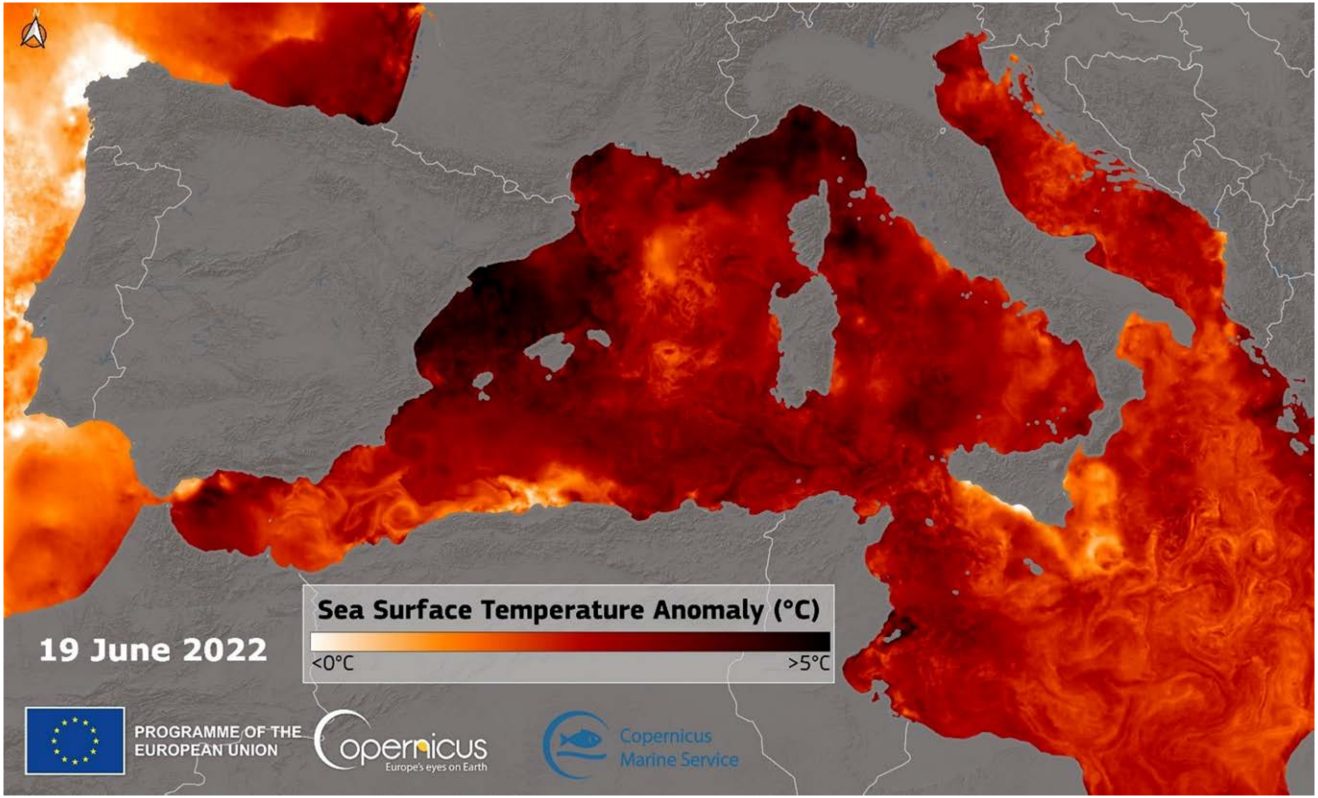

Figure 1 – Sea Surface Temperature anomaly in the Mediterranean, recorded on 19 June 2022. The data shows a thermal anomaly reaching +5°C along the Spanish, French and Italian coasts. Credit: *European Union, Copernicus Marine Service* [1].

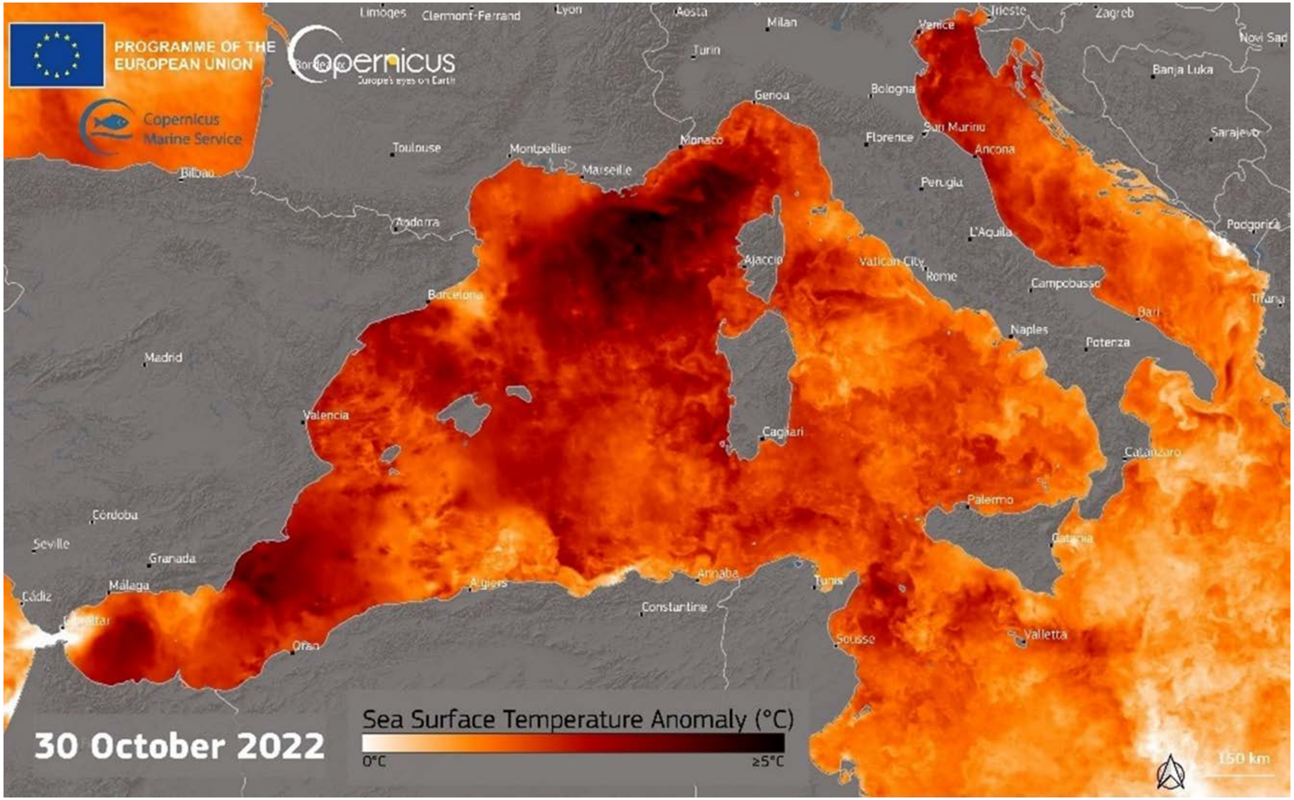

Figure 2 – Sea Surface Temperature anomaly in the Mediterranean, in October 2022. Credit: *European Union, Copernicus Marine Service data* [2].

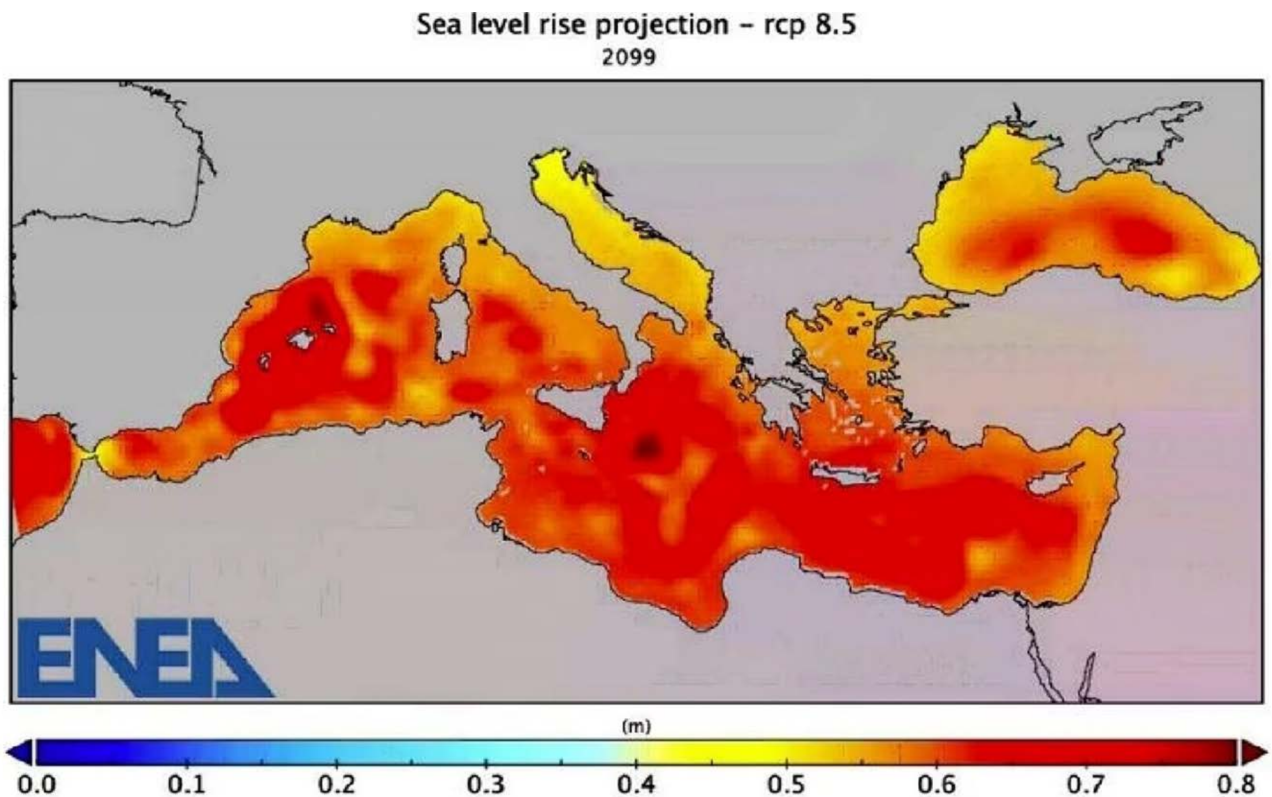

Figure 3 – Mediterranean Sea Level Rise Projections 2100 without cuts in greenhouse gas emissions. *ENEA Processing* [3] [4].

Anthropogenic climate change has contributed to the rise in the average level of the Mediterranean Sea by more than 25 centimeters in the last 130 years.

The particular configuration of this sea makes the still ongoing phenomenon more evident than in the oceans.

The Mediterranean is a semi-enclosed basin, with relatively high mountains in the western countries and low coasts in the south-eastern areas, with a not very high average depth (1430 m) and small extension (just 0.82 % of the total surface of seas and oceans). As a result, the water level rise, even just due to thermal expansion because of overheating, occurs more rapidly than in the oceans. As a result, water levels are rising faster than in the oceans, even if only due to thermal expansion because of overheating.

According to ENEA[3] forecasts [4], if the current increase in global temperature is not reversed, in 80 years the level of the Mediterranean will be about 60 centimeters higher than today's level (figure 3).

The rising level of the Mediterranean has increasingly serious consequences that may lead to the disappearance of all current ports. Figure 4 shows the forecast for 2100 of the risk of floods and *storm surge*[4] on the Italian coasts. [5]

Figure 4 – Scenario 2100 on the Italian coasts at risk due to the rising level Mediterranean: harbours at flooding risk or storm surges. *ENEA elaboration* [5].

The rise in the Mediterranean Sea level is, and will increasingly be, due essentially to:

- Melting ice: Greenland, Antarctica[5];
- Melting glaciers: Alpine ones with an ice loss of 5 km^3 so far;
- Low pressures: intermittent, *Medicane*[6].

In particular, in the Arctic region, climate change has had a considerable effect on sea level due to: warming of the Arctic Ocean; declining of the Greenland ice sheet; melting of glaciers in Alaska and the Svalbard archipelago; thawing of permafrost in Siberia and increased freshwater flow from Arctic rivers [7]. [7]

Regarding the Alpine region, an increase in the average air temperature of about 2 °C has been observed between the end of the 19th century and the beginning of the current century, more than the double that observed for the entire Northern Hemisphere (0.8 °C). Therefore, it is estimated that since 1850, glacial areas in the Alps have decreased by about half. Since the 1980s, the reduction rate has accelerated [8, 9].

While the melting phenomena cause permanent increases in sea level, low-pressure systems, particularly Mediterranean cyclones known as *medicanes* (Figure 5) produce sea level rises that lead to significant flooding well beyond coastal areas, that gradually shrink once the phenomenon has ceased.

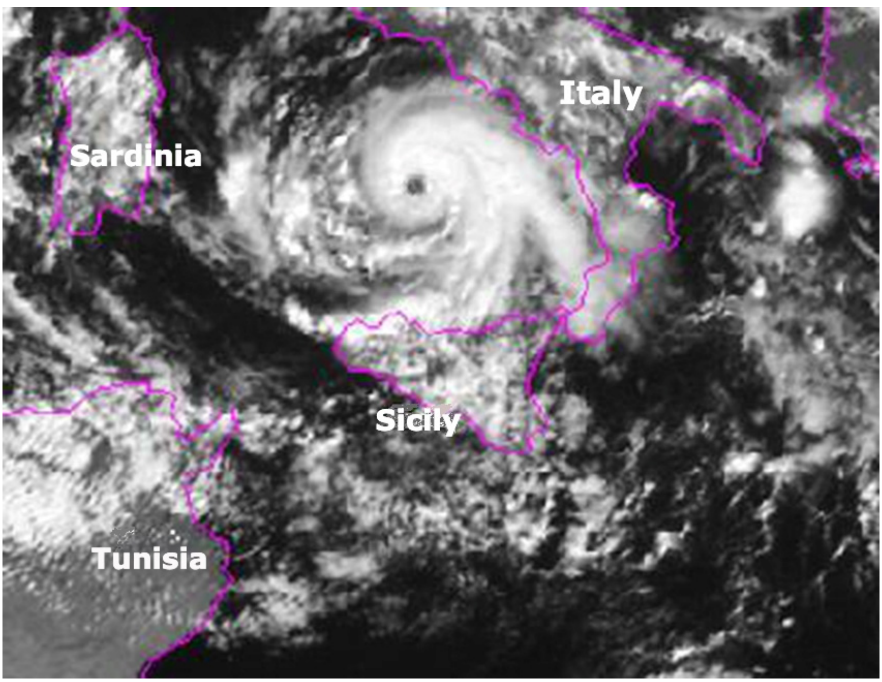

Figure 5 – Medicane *MEDIterranean hurricane*: Mediterranean cyclone with characteristics like tropical cyclones, the eye of the cyclone is clearly visible in the center of the spiral. In the figure Mediterranean Hurricane *Cornelia* (October 9th, 1996). Source *Nasa Dundee* [11] [12].

Other side effects of increased seawater temperature include:

- *Seawater Acidification* [8]; it is caused by the absorption of excess CO_2 produced by human activities; in the Mediterranean, we can observe today a pH values range from 8.13 to 7.95. At values below 7.8, many marine species could face extinction [13].
  Marine ecosystems could "give" much more if correctly used.
- *Decrease in biodiversity*; in the Mediterranean are estimated to be 17 000 species, corresponding to 7,5 % of the world's marine fauna. However, these numbers can rapidly decline due to climate change and the increasing presence of micro and macro plastics in the waters.
  The balance of ecosystems is threatened even by the disappearance of a single species.

Nature is balanced like a house of cards:
fragile, each card supports the other, if one falls…….

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Endnotes

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[1] Gulf Stream: warm ocean current that originates in the Gulf of Mexico, at 27 °C and, through the Atlantic, and reaches Northern Europe (with a maximum flow rate of 74 million m^3/s), with a temperature water at 20 °C, mitigating the climate of its coasts. [*ED. =Editor's Note*].
[2] For example, consider two sites at the same latitude, about 52° N, such as London, whose average annual temperature is about 13 °C, and Labrador City, a small town near the Canadian east coast, whose average annual temperature is -3 °C; without the effect of the Gulf Stream, London might find itself living with a temperature of -3 °C. *[ED]*.
[3] ENEA former *Ente Nazionale Energia Alternativa* actually *Italian National Agency for New Technologies, Energy and Sustainable Economic Development. [ED]*.
[4] Storm surge is a coastal flooding phenomenon caused by an anomalous rise in sea level, above the predicted astronomical tide, generated by a storm (low pressure weather systems) Storm surge is primarily caused by the strong onshore winds of a hurricane or tropical storm. The wind circulation around the eye of a hurricane causes a vertical circulation in the ocean. While in deep water, there is no indication of storm surge because there is nothing to interfere with this circulation. However, once the storm reaches the shallower waters near the coast, the vertical circulation is disrupted by the ocean bottom. The water can no longer move downward, so it begins to move upward and inland, resulting in storm surge [6]. [*ED*],
[5] It can be noted that the Arctic polar cap is not mentioned, as it is floating; unlike the Antarctic ice pack, it does not rest on land. The melting ice from the Arctic cap causes an uplift of the cap while leaving sea level virtually unchanged. Similarly, the summer reduction of polar ice pack has a negligible effect, as the ice that melts is floating and thus in equilibrium with sea level [7]. *[ED]*.
[6] The term *Medicane* is a contraction of the locution "Mediterranean Hurricane" (also known as TLC: *Tropical Like Cyclone*); it indicates a super-low-pressure system that produces a quasi-tropical cyclone in the Mediterranean characterized as follows:

- Decrease in the barometric pressure trend by 1 hPa/hour for at least 24 hours.
- Superadiabatic lapse rate even above 30° N latitude.
- Wind force 12 (*hurricane-force* >118 km/h or 65 kn).
- Average rainfall rate up to 500 mm/h.
- Diameter 200÷400 km.
- Duration 24÷48 hours.

[7] Since the *thermal equilibrium* of the 1970s and 1980s, when the climate was colder than it is today, ice loss has increased by about 20 billion tons each year. [7] *[ED]*.
[8] It has been observed that in the last two centuries, due to increasing CO_2 emissions, oceanic pH has dropped from 8,2 to 8,1; currently, the oceans are about thirty percent more acidic (the more accurate expression is less basic, as acidity begins with a pH below 7) than they were before the Industrial Revolution. If this trend continues at the same rate, it is hypothesized that by the end of this century, the pH will decrease to 7,8. Therefore, at least one third of marine species would disappear, and coral reefs would be wiped out in just a few decades [10]. *[ED]*.

SESSION

FLORA AND FAUNA OF COASTAL ECOSYSTEMS: PROTECTION, MANAGEMENT, MONITORING

Chairperson: Davide Travaglini
Department of Agriculture, Food, Environment and Forestry
University of Florence

FLORA AND FAUNA OF COASTAL ECOSYSTEMS: Protection, Management, Monitoring

Coasts are ecotones between sea and land. Coastal ecosystems are highly dynamic, they interact with different land use systems and are often in direct contact with urban environments, where the pressure of human activities on the coast is high. All these features make up a complex environment so that its flora and fauna show particular morpho-physiological, ecological and behavioral adaptations.

In 2024, a total of 30 papers have been published in the Proceeding of the Session *Flora and fauna of coastal ecosystems: protection, management, monitoring* of the 10th Symposium "Monitoring of Mediterranean coastal areas: problems and measurement techniques".

The topics covered by the submitted papers refer to different issues, such as biodiversity monitoring and conservation, invasive alien species, water quality status. Here follows a very short introduction to the contents of the papers.

Coastal ecosystems are rich in biodiversity, and the conservation of biological diversity in these environments was the subject for many researchers.

Amphipods diversity was studied by three research groups. Badalucco et al. reported a revised checklist of amphipod crustaceans from the Italian and Mediterranean seas as a contribution to provide a systematic and comprehensive analysis of species occurrence, which is essential for biodiversity assessment and monitoring.

De Simone et al. observed the recruitment of amphipod species on submerged artificial structures that were installed between the Lazio coast and Sardinia, in Italy.

In the North Adriatic Sea, Marusso and Trabucco monitored the influence of the installation of the first offshore liquefied natural gas terminal on the Amphipoda and Cumacea communities.

Galatolo and Schembri studied the epibiotic assemblages in the Maltese islands.

Regarding habitat monitoring in coastal environments, Bahbah et al. reported the results of the first large-scale mapping of supralittoral, mediolittoral and upper infralittoral benthic rocky substrate habitats of the Algerian coast.

Gennaro et al. tested the standardized coralligenous evaluation procedure on subregion scale under different human pressures for the evaluation of the ecological quality of coralligenous cliffs in the Mediterranean Sea.

The Coastal Health Monitoring Scheme as an example of educational approach, engaging students in projects with practical social value was described by Pinya et al.

Resaikos et al. discussed the advantages that research divers can have using electronically-controlled, closed-circuit, mixed-gas rebreathers for conducting ecological survey of marine habitats.

FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Laura Bonora, Marcantonio Catelani, Matteo De Vincenzi, Giorgio Matteucci (edited by), *Tenth International Symposium "Monitoring of Mediterranean Coastal Areas: Problems and Measurement Techniques". Livorno (Italy) 11th-13th June 2024*, © 2024 Author(s), CC BY-NC-SA 4.0, published by Firenze University Press, ISBN 979-12-215-0556-6, DOI 10.36253/979-12-215-0556-6

Marine protected areas play a critical role in conserving marine biodiversity, safeguarding habitats, and ensuring the sustainability of marine resources, and effective monitoring is fundamental to the success of marine protected areas. To this end, Capurso et al. evaluated the current management and monitoring status of Mediterranean of marine protected areas and assessed the application and potential of environmental DNA metabarcoding for biodiversity monitoring.

Other studies were carried out on the marine environment. Sureda et al. studied the effects of salinity and ectoparasite on *Coris julis* (Linnaeus, 1758).

Rahmani and Mokrane examined histological indicators correlated with macroscopic reproductive parameters in male and female of European anchovy (*Engraulis encrasicolus*). Tejada et al. assessed the antioxidant and immune responses in mucus and spleen of *Xyrichthys novacula* specimens, that are infected by *Scaphanocephalus* sp.

Bundone et al. reported the results of the monitoring programmes carried out on the endangered Mediterranean monk seal in the central Mediterranean Sea.

Water quality status plays a critical role for biological life, from primary producers to fish communities.

The ecological and chemical status of transitional waters systems in Sicily was evaluated by Bellissimo et al.

Busuttil et al. recorded abiotic and ecological conditions across the Salini saltern complex in Malta and related them to the external marine conditions.

Pinardi et al. used hyperspectral and multispectral satellite data to map water quality and submerged vegetation in the gulf of Oristano, Italy.

Marine invasive species alter the environment in which they settle, changing food chains, generating structural variations and, sometimes, displacing native species.

Bonin-Font et al. used an autonomous underwater vehicle to monitor the coverage and expansion rate of Halimeda incrassata in the Balearics.

Budiša et al. reported the results of a monitoring programme of gelatinous zooplankton in the northeastern Adriatic coast.

The impact of the blue crab *Callinectes sapidus* on the Mellah Lake was reported by Becir et al.

Curatolo et al. reported a review of genetic and morphological published data as a supporting baseline for the taxonomic issues of the *Brachidontes pharaonis* + *variabilis* group.

The remaining studies focused on land environment.

Camilleri and Lanfranco used UAVs to evaluate a vegetation reinforcement programme in a coastal area in Malta and compared its accuracy and cost-effectiveness with that of ground-based methods.

Cesaraccio et al. described a prototypal monitoring system based on repeated digital images for detecting changes in phenological traits of Mediterranean coastal maquis in North-West Sardinia.

Chiesi et al. applied a model combination strategy to analyse gross and net production in a Mediterranean pine wood ecosystem in Central Italy.

Galletti et al. used UAVs for monitoring *Caretta caretta* turtle nests in Tuscany, Central Italy.

Canzanella et al. did a study to quantify inorganic chemical contaminants in organs, tissues, and eggs of *Caretta caretta*.

Lombardi et al. presented a novel approach for local-scale quantification of stand plant transpiration in a coastal Mediterranean forest under climate change.

Morabito et al. assessed the impact of urbanisation on the conservation status of coastal habitats in Calabria, Southern Italy.

Yahi et al. assessed the conservation status of coastal habitats in Algeria.

As for invasive species, Falanga et al. used PlanetScope images with the objective of evaluating the effectiveness of remote sensing in monitoring *Toumeyella parvicornis* (Cockerell) (Hemiptera: Coccidae) infestation on coastal and urban *Pinus pinea* L. stands.

Cini et al. assessed the time and cost-effectiveness of three monitoring methods (photointerpretation, machine learning classification, and field monitoring) for detecting and mapping alien plants (Yucca gloriosa) in coastal dunes in Central Italy.

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CHECKLIST OF AMPHIPODS OF THE ITALIAN SEAS: BASELINE FOR MONITORING BIODIVERSITY

Antonina Badalucco, Rocco Auriemma, Andrea Bonifazi, Roberta Cimmaruta, Elvira De Matthaeis, Cristina Gioia Di Camillo, Valentina Esposito, Davide Iaciofano, Traudl Krapp, Leonardo Latella, Loretta Lattanzi, Marco Lezzi, Monica Lionello, Emanuele Mancini, Agnese Marchini, Veronica Marusso, Ermelinda Prato, Felicita Scapini, Maria Beatrice Scipione, Monica Targusi, Francesco Tiralongo, Benedetta Trabucco, Alberto Ugolini, Sabrina Lo Brutto

Abstract: This preliminary study presents an updated checklist of amphipod crustaceans inhabiting Italian seas and provides valuable insights into their diversity, distribution, and ecological traits. By combining existing literature with unpublished data, we were able to record 500 species in Italian waters. The analyses revealed a significant increase in the number of amphipod species documented in the Country, primarily due to intensified research efforts and the introduction of non-native species. This study highlights the importance of ongoing monitoring and research to assess marine biodiversity. Future efforts should prioritize understudied groups, such as planktonic species, and those living in deep-sea marine environments.

Keywords: Amphipoda; Italian Checklist; Mediterranean Biodiversity

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Introduction

This study presents the preliminary data of the revised checklist of amphipods of the Italian seas as a contribution to a comprehensive analysis of species occurrence, which is essential for biodiversity assessment and monitoring activities.

The amphipods are an abundant and ecologically important component of the marine communities [6, 8]. They include species belonging to different trophic and ethological categories and play a pivotal role in the ecology of marine habitats [4, 7]. The amphipods are particularly sensitive to chemical and physical changes and respond relatively quickly to natural and anthropogenic stress factors [2, 6] therefore, they can be used as bioindicators for monitoring the marine environment.

In this context, the updating of species checklists can be considered a tool of fundamental importance to better understand the spatial and temporal evolution of the changes that biodiversity can undergo. Unfortunately, the amphipod fauna is often overlooked. A comprehensive study on the geographical distribution and ecology of the benthic amphipods of the Mediterranean Sea was edited by Sandro Ruffo between 1982 and 1998 aimed mostly at the taxonomic identification of species. It included about 450 species [9], while the information on pelagic amphipods came only from a few articles [3]. Later, in 2010, Ruffo focused on the Italian fauna and compiled the first checklist of marine amphipods, which included 457 species, both benthic and pelagic [10].

The aim of this work was to provide up-to-date information on the amphipod fauna of the Italian seas and to show whether it is representative of the Mediterranean Sea.

Materials and Methods

A review of the available literature was carried out. Unpublished data, including those from various surveys, were combined with the lists of scientific articles. The literature search was conducted through the tool “Advanced Search” of Google Scholar using the keywords “checklist”; “Italy”; “Italian”; “amphipod*”; “peracarid*”; “Crustacea*”. To date, more than 100 papers have been consulted. In order to make a comparison with the records of the entire Mediterranean Sea, a similar search was conducted replacing the keyword ‘Italian’ with ‘Mediterranean’. To date, more than 60 papers have been consulted with updated records from the Mediterranean region, outside Italian waters. A new update on the number of species in Italian waters and, concurrently, in the Mediterranean Sea has been obtained. The nomenclature of all species has been updated in accordance with the World Amphipoda Database [5]. A dataset was created for all the Mediterranean species, in which the amphipod species were assigned to different ecological and biogeographical traits, i.e. zoogeographical distribution, bathymetry and substrate preference.

Results

The project, which involved several institutions, produced preliminary results that updated the Italian checklist to 500 species, differently present in the various biogeographical sectors (Figure 1); seven species were non-indigenous species (NIS), bringing the total number of NIS present in Italy to 11.

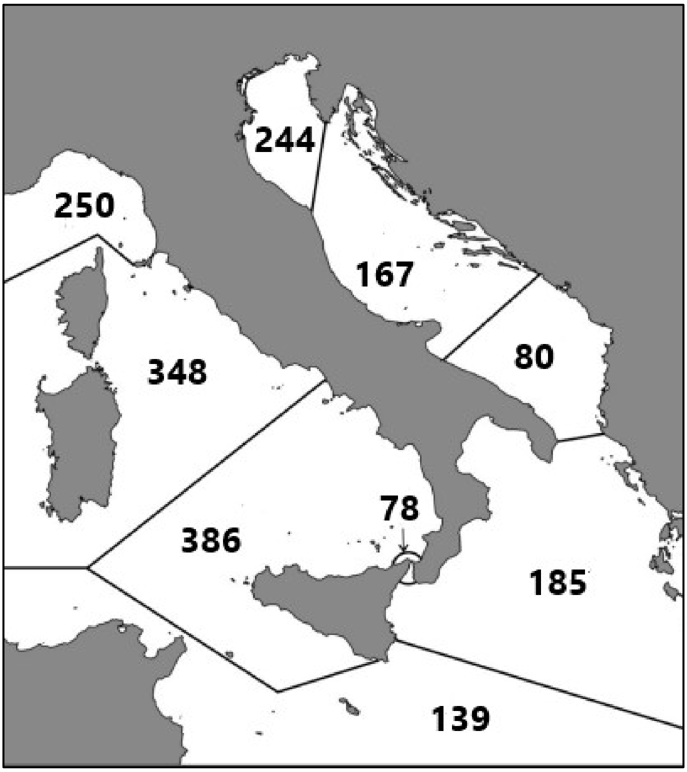

Figure 1 – Map of Italy representing the division of the Italian seas into nine biogeographic sectors. Numbers indicate species richness in the various sectors.

The total number of Mediterranean amphipods recorded in this first revision was 646 (Figure 2), including the Italian species.

Species richness is illustrated by categorising the Italian seas into the nine biogeographical sectors [1] (Figure 1), and the Mediterranean Sea into the two sub-basins (western and eastern) (Figure 2). Regarding Italy, 352 records reported species in sectors where they had not previously been recorded.

The update of the Italian checklist has contributed to expanding our knowledge of the entire Mediterranean fauna, which currently counts 581 species in the western basin and 525 in the eastern basin.

In order to obtain a complete overview of the amphipod fauna in the Mediterranean region, a dataset was created including information on ecological and biogeographical traits. The Mediterranean endemic species were 205; the Atlanto-Mediterranean species 277; the cosmopolitan species 149; the NIS 15 (Figure 3).

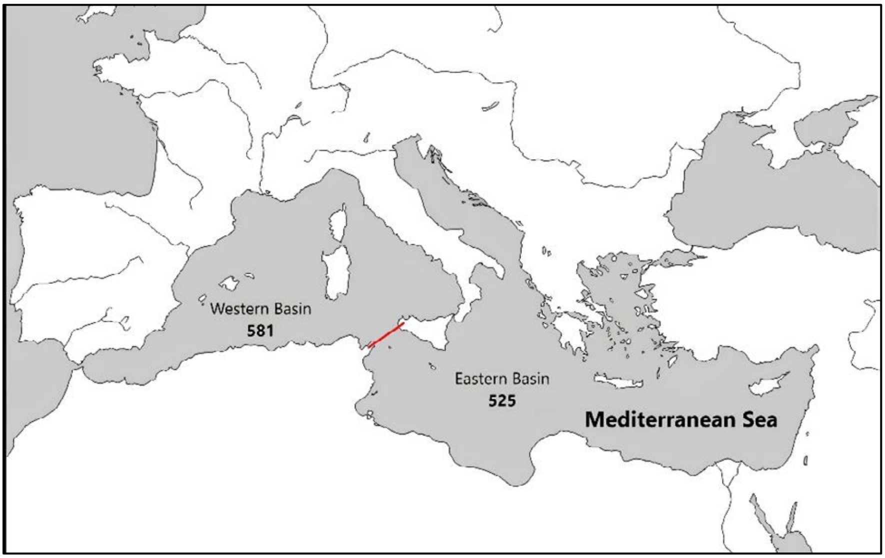

Figure 2 – Map representing the Mediterranean Sea divided into two sub-basins (western and eastern). Numbers indicate species richness in the two sub-basins.

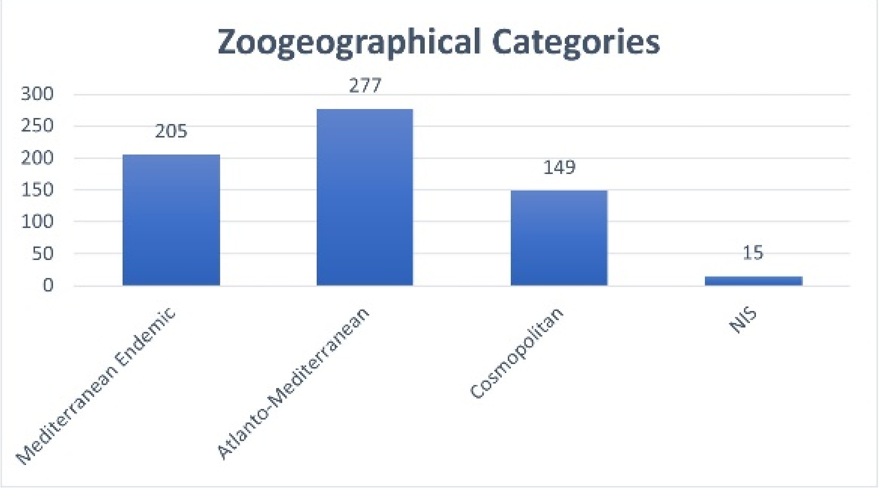

Figure 3 – The Mediterranean amphipod species assigned to categories according to zoogeographical distribution.

In terms of bathymetric categories, the supralittoral species (semi-terrestrial amphipods) were represented by 2 %; mesolittoral species by 11 %; infralittoral species by 35 %; circalittoral species by 28 %; bathyal species by 17 %; abyssal species by 3 % and species with no information by 4 % (Figure 4).

The amphipod species were also categorised according to their general substrate preferences: vegetal substrates (both algae and marine phanerogams), soft bottom, hard bottom, artificial substrates (fouling). Vegetal substrates accounted for 28 %, soft bottoms for 44 %, hard bottoms for 17 %, artificial substrates for 4 % and the species for which no information was available for 7% (Figure 5).

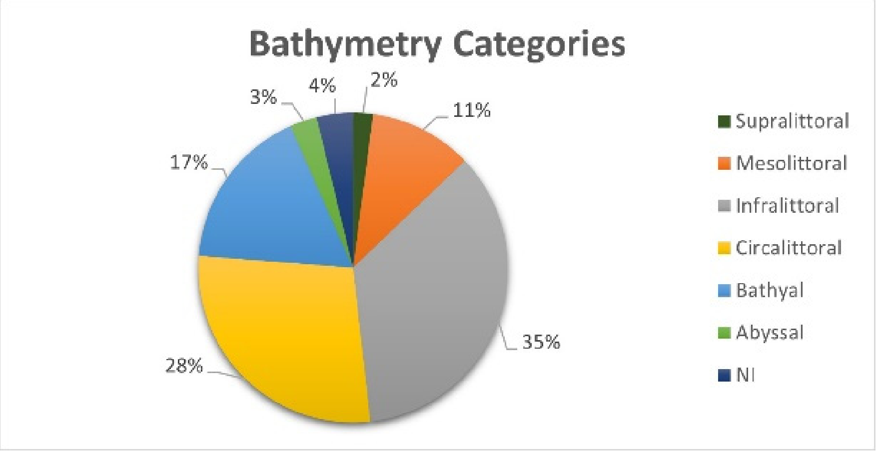

Figure 4 – Percentage of the Mediterranean amphipod species assigned to categories based on bathymetry.

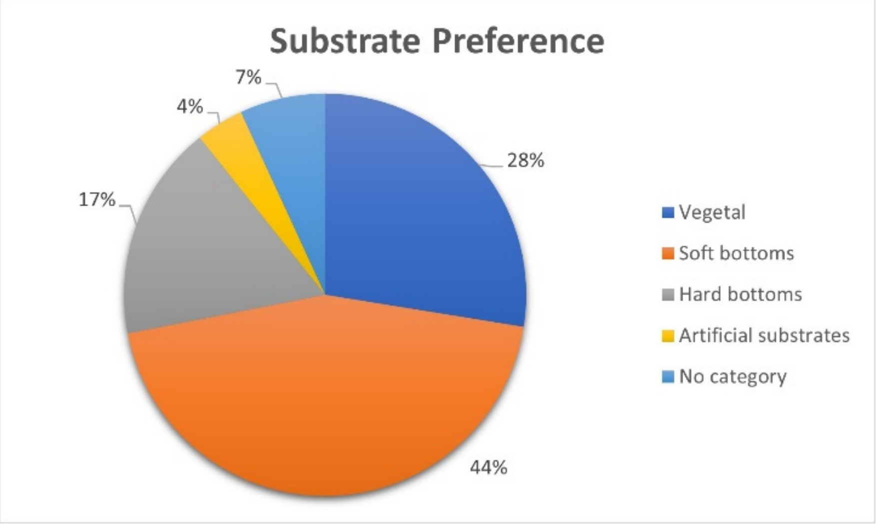

Figure 5 – Percentage of the Mediterranean amphipod species assigned to categories according to substrate preference.

In terms of bathymetric categories, the supralittoral species (semi-terrestrial amphipods) were represented by 2 %; mesolittoral species by 11 %; infralittoral species by 35 %; circalittoral species by 28 %; bathyal species by 17 %; abyssal species by 3 % and species with no information by 4 % (Figure 4).

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Discussion

This preliminary study provides a comprehensive and up to date overview of the diversity and distribution of amphipod crustaceans in the Italian seas. The analysis revealed that the number of amphipod species recorded in Italy has increased considerably.

Updating the checklists is an important step towards a better understanding of marine biodiversity in the Italian seas and in the Mediterranean in general.

Thorough knowledge of this taxon is essential for assessing the state of marine ecosystems, as amphipods are sensitive indicators of environmental conditions and can be used to monitor the impact of human activities on marine ecosystems; for biodiversity management, as the identification of endemic and threatened species can guide conservation and management strategies for marine biodiversity and for a better understanding of ecological processes; the study of amphipods can provide valuable information on ecological processes that occur in marine ecosystems, as they are an important link between primary producers and higher-order consumers, and are an ecologically important group contributing to nutrient cycling.

In conclusion, the species included in the checklist of Italian seas, which represent 76.7 % of the species present in the Mediterranean Sea, indicate that the Italian seas play a central role in the amphipod diversity of the Mediterranean Sea. Nevertheless, further sampling and monitoring efforts are advisable, especially for planktonic species for which there are very few new records, for parasitic amphipod species and for species living in extreme marine environments.

Acknowledgements

Project partially funded under the National Recovery and Resilience Plan (NRRP), Mission 4 Component 2 Investment 1.4 — Call for tender No. 3138 of 16 December 2021, rectified by Decree n.3175 of 18 December 2021 of the Italian Ministry of University and Research funded by the European Union — NextGenerationEU; Project code CN_00000033, Concession Decree No. 1034 of 17 June 2022 adopted by the Italian Ministry of University and Research, CUP D33C22000960007 and CUP B73C22000790001, Project title "National Biodiversity Future Center — NBFC".

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MAPPING OF BENTHIC ROCKY SHORE HABITATS OF THE ALGERIAN COAST (SOUTH-WESTERN MEDITERRANEAN)

Lamia Bahbah, Bilel Bensari, Khadidja Chabane, Halima Seridi, Simone Mariani, Enric Ballesteros

Abstract: This study is the first large-scale mapping of supralittoral, mediolittoral and upper infralittoral benthic rocky substrate habitats of the Algerian coast. It is a first step to fix the lack of cartographic information and general knowledge of coastal marine habitats in Algeria. 2D digital habitat mapping was carried out along 450 km of coastline using CAT-LIT methodology. We also provide a reference database of the coastal marine habitats of the Algerian coast, named "List of ALGerian MARin HABitats". Natural rocky coastlines are the dominant typological category in the area. The coastline studied is highly diverse in terms of habitats, since 35 benthic habitats were identified. Supralittoral benthic communities are dominated by barnacle *Euraphia depressa* and the lichen *Verrucaria amphibia*. Barnacles (*Chthamalus* spp.) and the red alga *Rissoella verruculosa* occupy the upper mediolittoral zone, while habitats dominated by the red algae *Ellisolandia elongata* and *Lithophyllum byssoides* characterize the lower mediolittoral zone. The upper infralittoral fringe is dominated by *Ellisolandia elongata* and rockweed *Ericaria selaginoides* in exposed shores or by *Gongolaria barbata* in sheltered areas. These habitats represent the core habitats of the littoral zone of Algeria. Anthozoans *Astroides calycularis* and *Actinia equina* are common in the infralittoral zone. Ulvales are abundant in Algiers Bay indicating polluted waters.

Keywords: Cartography, Macroalgae, Marine Habitats, Coastal Ecosystems

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Lamia Bahbah, Bilel Bensari, Khadidja Chabane, Halima Seridi, Simone Mariani, Enric Ballesteros, *Mapping of benthic rocky shore habitats of the algerian coast (south-western mediterranean)*, pp. 14-38, DOI: 10.36253/979-12-215-0556-6.02

Introduction

In spite of the many definitions in the literature (see [19]), here we define the habitat as a natural system characterized by its own environmental conditions and the assemblages of organisms that inhabit it at definite, albeit dynamic, spatial and temporal scales. Coastal areas exhibit strong gradients of environmental conditions which continuously keep most species within their tolerance limits. In many coastal areas, this feature helps the recognition of different arrays of habitats dominated by one or several species of benthic organisms.

Habitat classifications aim to define habitats in a coherent way, thus allowing their comparison across different geographical regions or periods. As for marine habitats, several classifications and typologies have been established in Europe and North America, such as ZNIEFF-mer, CORINE biotopes, Natura 2000, EUNIS, CMECS, and LPRE. Thanks to the newest digital mapping techniques [17] and the existence of habitat typologies, the responses of coastal habitats to environmental disturbances, for instance, whether natural or anthropogenic, can be better on at different geographical scales

In Algeria, the classification of marine habitats was nonexistent, and knowledge about the marine and coastal environment remained very poor. The present study aims at: 1) Establishing the first reference framework for coastal rocky substrate habitats from the Algerian coast; 2) creating detailed maps of these habitats at a scale of 1:1500 using the catenas method from CAT-LIT (see the Materials and Methods session and [19]); 3) and assessing the relationships between them through network analysis.

Materials and Methods

Study Area

The geographical area covered by this study corresponds to the central Algerian coast (Figure 1). It includes four cities from east to west: Boumerdes, Algiers, Tipaza, and Chlef. The study area extends from Cap Djenet in the east (Boumerdes) to Cap Tenes in the west (Chlef), encompassing approximately 450 km of coastline. The coastal geomorphology consists of a succession of cliffs, rocky and sandy bays, scattered with rocky promontories and beaches. The study region includes the bays of Zemmouri, Algiers, and Bou Ismail, with several river mouths. Additionally, there is a major commercial port (Algiers Port) and 11 fishing ports.

Data Collection

The "Algerian Marine Habitats" (ALG-MAR-HAB) is based on widespread typologies such as CORINE Biotopes and EUNIS, as well as the LPRE classification. In situ identification of dominant benthic habitats was conducted over a period of three years (2016-2021). Information on dominant species, substrate type, accompanying species, wave exposure, bathymetric level, substrate mode, and topography was recorded at each site. More concretely, the environmental characteristics considered for habitat classification included:

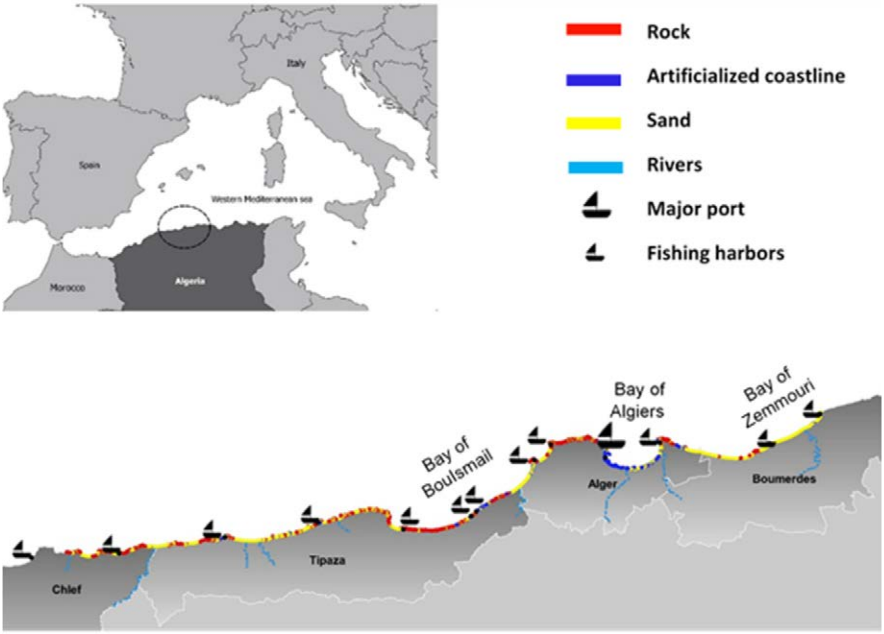

Figure 1 – Geographical Positioning of the Study Area.

- *Substrate type*: Rocky, sandy, muddy, gravel.
- *Bathymetric level*: Three zones were considered in this study:
  - Supralittoral Zone: More or less regularly-wetted, never-submerged.
  - Mediolittoral Zone: Intermittently-submerged.
  - Infralittoral Zone: Almost permanently submerged.
- *Wave exposure*: sheltered, moderately exposed, or exposed.
- *Substrate topography*: "plateaus", caves, overhangs, hollows and ridges, tide pools.

Habitat Mapping

This approach includes both data collection from the field and data entry into digital databases. Data collection consisted in mapping the rocky littoral habitats while steering along the coastline on a small boat. Where the access by boat was challenging, mapping was done directly from the shore on foot or by snorkeling. Prior to the characterization of the different habitats, (see [19]), we mapped different horizons or belts dominated by a specific organism or organisms and recorded this information on a paper map (A4 format). The scale was set at 1:1500, and the mapped coastal sectors measured at least 10 meters, except for some horizons from specific environments (e.g., caves, rock pools), where the sampling unit was scaled to the area they occupied, and the exact position recorded by GPS, applying the WGS84 reference system. The data was recorded *in situ* using orthophotos.

To validate the identification of uncertain species we collected samples for the identification in the laboratory. The entire sampling process took place over three months, from May to August 2018-2021, during the peak in the annual development period of algae.

The task of recording all the horizons in a particular spot was much simplified by using the catena methodology from [19]. Our methodology, in fact, draws inspiration from the CAT-LIT method ("CATenas" and "LITtoral"), modified and adapted to the Algerian coast. First, we needed to clarify the definition and differentiation of these operational units (the horizons and the catenas), the equivalence or overlap between existing terms, and the hierarchical relationships to establish a classification as unambiguous as possible (Figure 2).

Horizons: Subdivisions into bands defined by the dominant species in terms of biomass, cover, or number of individuals.

Catenas: Defined here as a series of horizons linked by their topographical occurrence, i.e., their position along the vertical axis, extending from the upper level of the supralittoral zone (about 50 cm on protected shores to over 10 m on more exposed shores) down to 1 m depth. The number of horizons in each sector varies from one to nine.

Figure 2 – Explanatory Image of Operational Units for Data Classification

An alphanumeric code was assigned to each catena, as shown in Annex 01, where each uppercase letter often refers to a group of similar catenas sharing characteristic horizons. For example, catenas A1 and A2 belonged to the same group because the horizons of the red alga *Rissoella verruculosa* and the brown alga *Ericaria selaginoides* were present in both, but they differed due to the dissimilarity in other horizons. This classification aims to conduct a precise study of the distribution of benthic habitats and facilitate the introduction of data into the GIS.

Digital mapping was developed using Geographic Information System (GIS) techniques with the QGis 3.12.3 program. The projected coordinate system was the WGS84. Digital mapping was carried out at a scale of 1:1500. Data were entered into a digitized linear vector, representing the central Algerian coastline. The digitized coastline was created from the most recent satellite imagery (2018) of the coastline.

As described above, each catena comprises several horizons, and each horizon could correspond to one or more habitats, most of which are described by the three classifications used: LPRE, EUNIS, and CORINE. Thus, the link between each catena and its corresponding horizons was stored in one table. Additionally, correspondences between horizons and habitats were stored in a third table. Finally, to have each habitat on a specific line segment, the habitat table was joined and connected to the line attribute table through a common field: HORIZON.

In summary, in QGis, after clicking on the "Information on a line segment" button, the corresponding catena, substrate, and segment length are displayed. Furthermore, by clicking on the Catena_Habitats link icons, the relevant horizons and their correspondences with different habitats (ALG-MAR-HAB, LPRE, EUNIS, and CORINE) are shown.

Data Analysis

Once the digital mapping is completed, a series of analyses can be performed directly from the project in QGIS 3.12.3. Firstly, general information such as the extent of substrate types, of the horizons and the catenas, and then the habitats (see below) can be easily obtained through queries. Secondly, the percentage cover of each habitat can be calculated relatively to the approximately 210 km of rocky shore. On the other hand, the percentage cover of each substrate type can be calculated relative to the total length of sampled coastline.

A network illustrating the relationships between rocky habitats (i.e. the number of times paired habitats coincided in the catenas) was visualized using the Gephi 0.8.2 beta program [8]. Each of the identified habitats was placed as a neighboring node by the Fruchterman-Reingold algorithm [11], before enhancing visualization using Gephi tools.

Results

Coastal Benthic Habitat Mapping

The mapping conducted is a 2D digital cartography of the horizons found along a coastline and grouped into different catenas. An excerpt of the mapping results is presented in Figure 3. It depicts approximately 6 km of the coastline with different line colors and labels for each Catena. By clicking the "identify" button, the habitats contained within each Catena are shown, along with the substrate type and the length of the segment occupied by that habitat. The list of existing catenas is provided in Annex 1.

By utilizing the same orthophotos both in the field and for digital mapping (Figure 3), we ensured a high level of consistency between the digital map data and the field-mapping values.

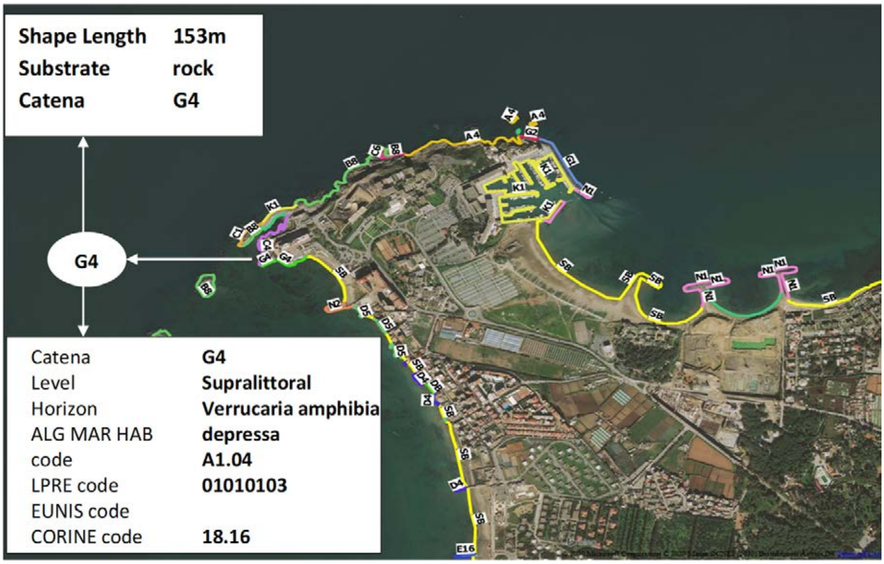

Figure 3 – Representation of the coastline showing different colors and labels for each Catena in QGIS.

Coastal Morphology

The most common substrate type along the studied coast was the natural rocky substrate (NHC), extending over 166.73 km of coastline. This was distributed between low coast (130.55 km; 28.11 %) and high rocky coast (cliffs; 36.20 km; 7.79 %). Furthermore, soft bottom represented 31.15 % of the coast. Artificial rocky coastline occupied a significant stretch, dominated by breakwaters (developed area) with 23.9 % and ports with 8.93 %. Concrete dykes represented less than 1% of the coast (Figure 4).

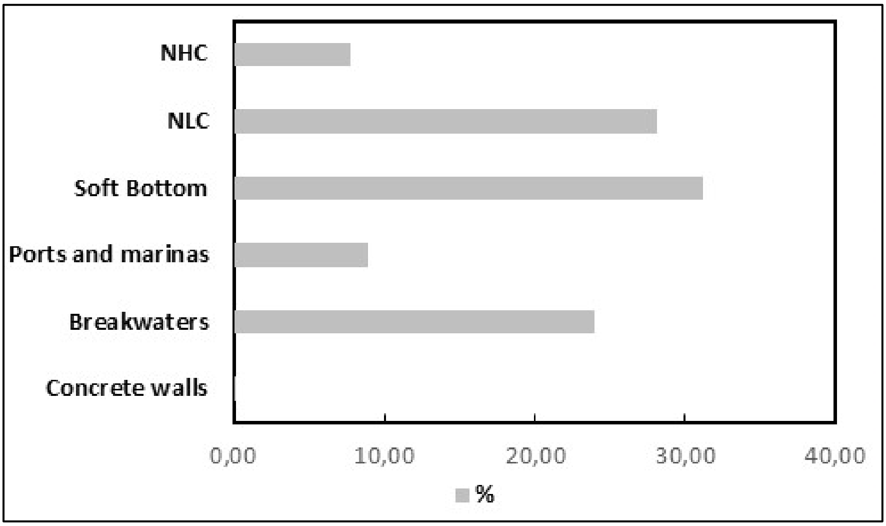

Figure 4 – Frequency of different mapped substrate types. NHC: Natural High Rocky Coastline, NLC: Natural Low Rocky Coastline.

Distribution of Benthic Habitats

We used 35 different horizons dominated by one species or different species guilds. These horizons corresponded to as many habitats in our final typology (see Annex 2).

Figure 05 shows the pattern of habitat abundance, calculated from the line lengths of each horizon, converted into percentages. None of the habitat studied exhibited a uniform distribution across the entire vertical gradient, with no habitat spanning all three zones. Some habitat show a narrow vertical distribution, like *Euraphia depressa*, *Rissoella verruculosa*, Trottoir, *Ericaria selaginoides*. Conversely, other habitats spread over a broader vertical range but with varying abundance, such as *Chthamalus* spp., *Ralfsia verrucosa*, *Lithophyllum* spp., *Gelidium* spp., *Halopteris scoparia*, *Mytilus galloprovincialis*, *Ellisolandia elongata*, and *Cystoseira compressa*.

The supralittoral rock is dominated by barnacle *Euraphia depressa* with lichen *Verrucaria amphibia* and some *Chthamalus* spp. The upper mediolitoral zone is defined by the habitat of *Chthamalus* spp. of the red alga *Rissoella verruculosa*. The lower mediolittoral rock is mainly populated by red alga *Ellisolandia elongata* and some mediolittoral algae forming carpets, and the upper infralittoral rock is covered whether by *E. elongata*, different photophilic algae and canopy-forming algae (*Ericaria selaginoides* and *Cystoseira compressa* in exposed coasts and *Gongolaria barbata* in sheltered coasts. (Figure 6).

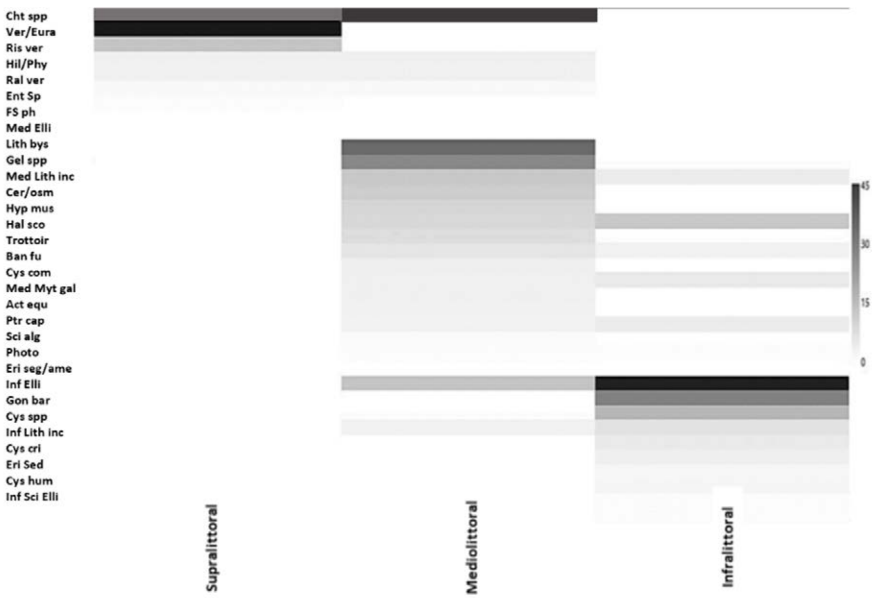

Figure 5 – Diagram illustrating the abundance (in percentage) of habitats along the vertical gradient of littoral zones.

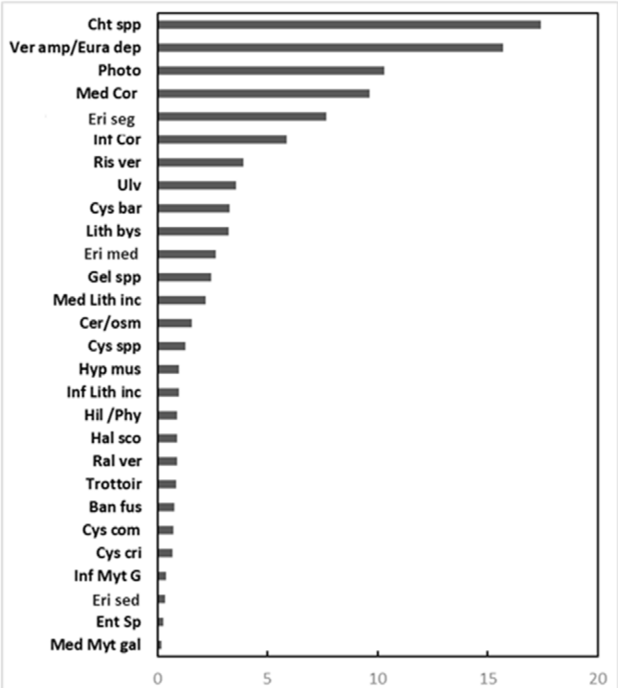

Figure 6 – Frequency of the most common habitats on rocky shores.

Habitat relations in the catenas

The diagram represented in Figure 7 depicts the degree of connection among the rocky habitats. It consists of a cloud of nodes of different sizes arranged in a decreasing gradient from the center to the edges, connected by links whose thickness depends on the degree of connectivity (the larger the link, the thicker the line). The most co-occurring habitats, such as *Verrucaria amphibia-Euraphia depressa* (Ver amp/Eura dep), *Chthamalus* spp. (Cht spp), and the mediolittoral habitat *Ellisolandia elongata* (Med Elli), are located in a central hub with larger node diameters (in brown) and thicker links between them. They are nearly ubiquitous but not connected to freshwater springs (FS ph). The orange nodes located near the center correspond to frequent habitats such as Ulvales (Ulv), photophilic algae (Photo), and infralittoral *Ellisolandia* (Inf Elli). The most frequent fucoids are *E. selaginoides/ amentacea* (Eri Seg/amen) in orange), while the less frequent ones are represented by small yellow nodes at the upper end of the diagram (*Cystoseira humilis, Ericaria sedoides, Ericaria crinita*). The least connected habitats are Freshwater Springs (FS ph), *Ulva* sp. (Ent Sp), and they are also the least frequent habitats.

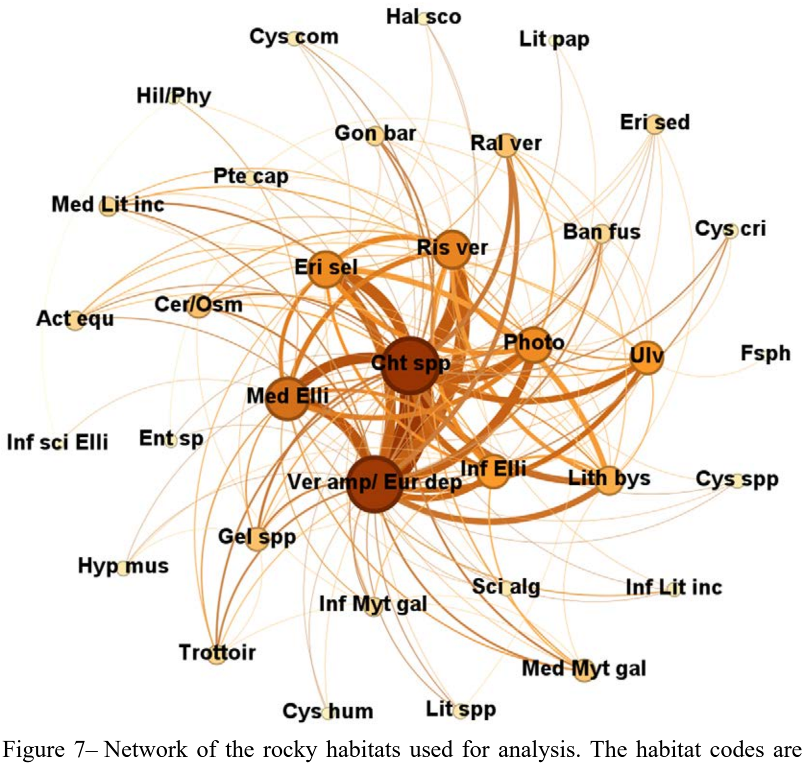

Figure 7– Network of the rocky habitats used for analysis. The habitat codes are listed in Table 2, along with the number of connections between them. The diameter of the nodes and the color darkness are relative to the degree of connections.

Table 2 – Habitat codes ranked by the number of connections between them.

COMMUNITY	CODE	Degree of CONNECTION
***Chthamalus* spp.**	Cht spp	33
Verrucaria amphibia – Euraphia depressa	Ver amp/Eura dep	33
Mediolittoral *Ellisolandia elongata*	Med Elli	26
Infralittoral *Ellisolandia elongata*	Inf Elli	24
Rissoella verruculosa	Ris ver	22
Photophilic algae	Photo	21
Ericaria selaginoides/amentacea	Eri sel	19
Ulvales	Ulv	19
Lithophyllum byssoides	Lith bys	17
Gongolaria barbata	Cys bar	15
Ralfsia verrucosa	Ral ver	14
***Ceramiales/Osmundea* spp.**	Cer/Osm	13
***Gelidium* spp.**	Gel spp	11
Lithophyllum incrustans	Med Lith inc	11
Hypnea musciformis	Hyp mus	11
Mediolittoral *Mytilus galloprovincialis*	Med Myt gal	10
***Hildenbrandia* sp./*Phymatolithon* sp.**	Hil /Phy	10
"Trottoir"	Trottoir	10
Bangia fuscopurpurea	Ban fus	9
Halopteris scoparia	Hal sco	9
Actinia equina	Act equ	7
Infralittoral *Mytilus galloprovincialis*	Inf Myt gal	7
Ericaria sedoides	Eri Sed	7
Cystoseira compressa	Cys com	6
Sciaphilic algae	Sci alg	5
Infralittoral *Lithophyllum incrustans*	Inf Lith inc	5
Pterocladiella capillacea	Ptr cap	5
Ericaria crinita	Eri cri	4
***Cystoseira sensu lato* spp.**	Cys spp	4
***Ulva* sp.**	Ent Sp	4
***Lithophyllum* spp.**	Lit spp	4
Cystoseira humilis sensu lato	Cys hum	3
Lithophyllum papillosum	Lith pap	3
Freshwater soringsq Photophilic algae	FS ph	1
Infralittoral sciaphilic *Ellisolandia elongata*	Inf Sci Elli	1

Discussion

Here we show the first map of the littoral habitats from the Algerian coast. In the first phase of this study 35 habitats were identified along the rocky coastline of the study area. The resulting set, distributed across the supralittoral, mediolittoral, and infralittoral zones, represented the dominant macrophytes and various sessile filter-feeding animals (mainly barnacles, mussels, bryozoans, and corals) from the study coast.

The habitats dominated by *Euraphia depressa* and *Verrucaria amphibia*, *Chthamalus* spp., and *Ellisolandia elongata* are almost ubiquitous. The subset of habitats formed by *Ericaria selaginoides/amentacea, Lithophyllum byssoides, Rissoella verruculosa,* and photophilic algae appears to be the most frequent after the first group. While these habitats are a measure of the extent of the mediolittoral and infralittoral rocky substrate influenced by moderate to strong waves (ALG-MAR-HAB, LPRE) and high light intensity, their presence of these habitats is evidence of good environmental quality [2]. However, the habitat of artificial coasts such as ports and marinas, spans over a significant portion of the studied coastline (57 km). This distribution allows for an assessment of the harbor walls colonized by organisms adapted to highly fluctuating environmental conditions or those that are very abundant due to a lack of effective competitors on poorly colonized substrates [19].

According to [3] and [21], climate-induced changes in distribution areas have influenced the evolution of a complex formed by three closely related *Ericaria* species which are a key element of Mediterranean and Atlantic seaweed forests experiencing demographic decline. The *E. selaginoides* complex, consisting of *E. tamariscifolia*, *E. amentacea*, and *E. mediterranea*, has indistinct boundaries, and natural hybridization is suspected [21]. Therefore, the term *Ericaria E. selaginoides/ amentacea* is here used to avoid confusion.

Cystoseira sensu lato forests are among the most important structural species in the Mediterranean, creating complex habitats essential for biodiversity and ecosystem functioning. Over recent decades, Mediterranean populations of *Cystoseira* s.l. have generally declined due to anthropogenic pressures [5]; [20]; [7]; [6]; [9]; [22]; [4]; [27]; [25]; [18]; [26]. Our study reveals that *Cystoseira* s.l. forests still exist in various areas along the Algerian coast, in both exposed conditions (*Ericaria selaginoides* complex*, Cystoseira compressa,*) and sheltered conditions (*Gongolaria barbata*, *Cystoseira foeniculacea,* and *Ericaria crinita).*

Biogenic concretions ("trottoir") such as those formed by the red *alga Lithophyllum byssoides* and platforms created by the algae *Neogoniolithon brassica-florida* and the gastropod *Dendropoma lebeche* (vermetid reefs) have been described in only a few locations along the Mediterranean coast. These species are sensitive to coastal disturbances (e.g., surface pollution, trampling) and serve as good indicators of sea level changes [13]; [14]; [15]; [16]; [10]. However, along the rocky coasts surveyed in this study, these bioconcretions were observed throughout the western region. The vermetid reefs appear to be better developed in areas such as Ténès, Beni Haoua, Sidi Ghiles, and Gouraya compared to the Tipaza coast.

Other species, however, thrive in polluted environments and are nitrophilic, tolerating high concentrations of nitrates and phosphates. For instance, Ulvales are frequently found in the Bay of Algiers, with *Ulva lactuca* and *Ulva rigida* being particularly prevalent. These species are considered reliable indicators for assessing eutrophication levels in marine ecosystems [12].

Among the identified habitats, some have no correspondence with other known typologies, such as the association with *Ericaria sedoides.* Notably, this species is also found in Sicily and Tunisia [1], [23]. Additionally, the habitat of mediolittoral caves with *Actinia equina* and *Astroides calycularis* stands out. The anthozoan *Astroides calycularis* has a limited distribution confined to the western Mediterranean, owing to its temperature tolerance [28] and preference for unpolluted environments [24]. In our study, this species was found in the mediolittoral zone, whereas other classifications indicate its presence starting only from the infralittoral zone. [24] provide evidence for the presence of this species from depths as shallow as 0 meters.

Apart from being the most abundant and frequent alga, the red coralline *Ellisolandia elongata* (mediolittoral and infralittoral), shows the highest degree of connections in the network and creates a central hub of connections with other habitats (Figure 7). This is not the case for other specific habitats, such as the mediolittoral cave habitat dominated by *Hildenbrandia rubra* and *Phymatolithon lenormandii*, and the freshwater spring habitat dominated by Ulvales, which both have a very modest number of connections and are rather unconnected to the rest of the network.

The habitat distribution and cover shown in this study will establish an important baseline, something that was lacking for the coast of Algeria. This "starting point" will allow the assessment of the evolution of these habitats and the effects of natural and human-induced disturbances in the study area. The evolution of the different assemblages and their responses to potential impacts, both in the short and the long term, will serve to detect changes in the shore and to investigate their causes.

Conclusion

The ALGMARHAB represents a unique and precise mapping and a comprehensive cartography about the spatial distribution of coastal habitats in Algeria. The use of catenas to map shoreline habitats has proven to be very practical and relevant, enabling the creation of detailed maps.

The ALGMARHAB list has been outlined and is ready to be expanded in the future as a tool for marine habitats monitoring and management. It will represent an invaluable tool to assess changes in habitat distribution and relate them with both natural and anthropogenic pressures.

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Annex 1 – Correspondence between catenaries and Horizons.

Code	N	Community
A1	1	Verrucaria amphibia – Euraphia depressa
A1	2	Chthamalus spp.
A1	3	Rissoella verruculosa
A1	4	Lithophyllum byssoides
A1	5	Hypnea spp
A1	6	Ericaria selaginoides
A1	7	Infralittoral Ellisolandia elongata
A2	1	Verrucaria amphibia – Euraphia depressa
A2	2	Chthamalus spp.
A2	3	Rissoella verruculosa
A2	4	Lithophyllum byssoides
A2	5	Mediolittoral Ellisolandia elongata
A2	6	Mediolittoral Mytilus galloprovincialis
A2	7	Ericaria selaginoides
A2	8	Infralittoral Ellisolandia elongata
A3	1	Verrucaria amphibia – Euraphia depressa
A3	2	Chthamalus spp.
A3	3	Rissoella verruculosa
A3	4	Lithophyllum byssoides
A3	5	Ericaria selaginoides
A3	6	Infralittoral Ellisolandia elongata
A4	1	Verrucaria amphibia – Euraphia depressa
A4	2	Chthamalus spp.
A4	3	Rissoella verruculosa
A4	4	Mediolittoral Ellisolandia elongata
A4	5	Ericaria selaginoides
A4	6	Photophilic algae
A5	1	Verrucaria amphibia – Euraphia depressa
A5	2	Chthamalus spp.
A5	3	Rissoella verruculosa
A5	4	Lithophyllum byssoides
A5	5	Ericaria selaginoides
A5	6	Infralittoral Ellisolandia elongata
A5	7	Ericaria sedoides
B1	1	Verrucaria amphibia – Euraphia depressa
B1	2	Chthamalus spp.
B1	3	Rissoella verruculosa
B1	4	Ulvales
B1	5	Ceramiales/Osmundea spp.
B1	6	Ericaria selaginoides
B1	7	Lithophyllum byssoides
B1	8	Actinia equina
B2	1	Verrucaria amphibia – Euraphia depressa
B2	2	Chthamalus spp.
B2	3	Rissoella verruculosa
B2	4	Ulvales
B2	5	Ericaria selaginoides
B2	6	Lithophyllum byssoides
B2	7	Actinia equina
B3	1	Verrucaria amphibia – Euraphia depressa
B3	2	Chthamalus spp.
B3	3	Rissoella verruculosa
B3	4	Lithophyllum byssoides
B3	5	Hypnea spp
B3	6	Ericaria selaginoides

Code	N	Community
B3	7	Infralittoral Ellisolandia elongata
B4	1	Verrucaria amphibia – Euraphia depressa
B4	2	Chthamalus spp.
B4	3	Rissoella verruculosa
B4	4	Ericaria selaginoides
B4	5	Infralittoral Ellisolandia elongata
B4	6	Photophilic algae
B5	1	Verrucaria amphibia – Euraphia depressa
B5	2	Chthamalus spp.
B5	3	Rissoella verruculosa
B5	4	Lithophyllum byssoides
B5	5	Mediolittoral Ellisolandia elongata
B5	6	Ericaria selaginoides
B6	1	Verrucaria amphibia – Euraphia depressa
B6	2	Chthamalus spp.
B6	3	Rissoella verruculosa
B6	4	Ericaria selaginoides
B6	5	Infralittoral Ellisolandia elongata
B6	6	Gongolaria barbata
B7	1	Verrucaria amphibia – Euraphia depressa
B7	2	Chthamalus spp.
B7	3	Rissoella verruculosa
B7	4	Lithophyllum byssoides
B7	5	Ericaria selaginoides
B7	6	Infralittoral Ellisolandia elongata
B8	1	Verrucaria amphibia – Euraphia depressa
B8	2	Chthamalus spp.
B8	3	Rissoella verruculosa
B8	4	Mediolittoral Ellisolandia elongata
B8	5	Cystoseira compressa
C1	1	Verrucaria amphibia – Euraphia depressa
C1	2	Chthamalus spp.
C1	3	Rissoella verruculosa
C1	4	litophyllum incrustans
C1	5	Mediolittoral Ellisolandia elongata
C1	6	Infralittoral Ellisolandia elongata
C2	1	Verrucaria amphibia – Euraphia depressa
C2	2	Chthamalus spp.
C2	3	Rissoella verruculosa
C2	4	Trottoir
C2	5	Mediolittoral Ellisolandia elongata
C2	6	Infralittoral Ellisolandia elongata
C3	1	Verrucaria amphibia – Euraphia depressa
C3	2	Chthamalus spp.
C3	3	Rissoella verruculosa
C3	4	Lithophyllym byssoides
C3	5	Mediolittoral Ellisolandia elongata
C3	6	Algues sciaphiles
C4	1	Verrucaria amphibia – Euraphia depressa
C4	2	Chthamalus spp.
C4	3	Rissoella verruculosa
C4	4	Mediolittoral Ellisolandia elongata
C4	5	Infralittoral Lithophyllum incrustans
C5	1	Verrucaria amphibia – Euraphia depressa
C5	2	Chthamalus spp.
C5	3	Hildenbrandia sp

Code	N	Community
C5	4	Rissoella verruculosa
C5	5	litophyllum sp
C6	1	Verrucaria amphibia – Euraphia depressa
C6	2	Chthamalus spp.
C6	3	Rissoella verruculosa
C6	4	litophyllum incrustans
C6	5	photophilic algae
D1	1	Verrucaria amphibia – Euraphia depressa
D1	2	Chthamalus spp.
D1	3	Rissoella verruculosa
D1	4	Mediolittoral Ellisolandia elongata
D1	5	Photophilic algae
D2	1	Verrucaria amphibia – Euraphia depressa
D2	2	Chthamalus spp.
D2	3	Rissoella verruculosa
D2	4	Ceramiales/Osmundea spp.
D2	5	Infralittoral Ellisolandia elongata
D3	1	Verrucaria amphibia – Euraphia depressa
D3	2	Chthamalus spp.
D3	3	Rissoella verruculosa
D3	4	Infralittoral Ellisolandia elongata
D3	5	Mediolittoral Mytilus galloprovincialis
D4	1	Verrucaria amphibia – Euraphia depressa
D4	2	Chthamalus spp.
D4	3	Rissoella verruculosa
D4	4	Infralittoral Ellisolandia elongata
D4	5	Photophilic algae
D4	1	Verrucaria amphibia – Euraphia depressa
D4	2	Chthamalus spp.
D4	3	Rissoella verruculosa
D4	4	Mediolittoral Ellisolandia elongata
D4	5	Mediolittoral Mytilus galloprovincialis
D4	6	Infralittoral Mytilus galloprovincialis
D4	7	Infralittoral Ellisolandia elongata
D5	1	Verrucaria amphibia – Euraphia depressa
D5	2	Chthamalus spp.
D5	3	Rissoella verruculosa
D5	4	Ulvales
D5	5	Ceramiales/Osmundea spp.
D5	6	Infralittoral Ellisolandia elongata
D6	1	Verrucaria amphibia – Euraphia depressa
D6	2	Chthamalus spp.
D6	3	Rissoella verruculosa
D6	4	Mediolittoral Ellisolandia elongata
E1	1	Verrucaria amphibia – Euraphia depressa
E1	2	Chthamalus spp.
E1	3	Lithophyllum byssoides
E1	4	Mediolittoral Ellisolandia elongata
E2	1	Verrucaria amphibia – Euraphia depressa
E2	2	Chthamalus spp.
E2	3	Trottoir
E2	4	Mediolittoral Ellisolandia elongata
E3	1	Verrucaria amphibia – Euraphia depressa
E3	2	Chthamalus spp.
E3	3	Trottoir
E3	4	Ericaria selaginoides

Code	N	Community
E3	5	Infralittoral Ellisolandia elongata
E4	1	Verrucaria amphibia – Euraphia depressa
E4	2	Chthamalus spp.
E4	3	Trottoir
E4	4	Gelidium spp
E4	5	Mediolittoral Ellisolandia elongata
E4	6	Ericaria selaginoides
E5	1	Verrucaria amphibia – Euraphia depressa
E5	2	Chthamalus spp.
E5	3	Trottoir
E5	4	Mediolittoral Ellisolandia elongata
E5	5	Mediolittoral Mytilus galloprovincialis
E5	6	Infralittoral Ellisolandia elongata
E6	1	Verrucaria amphibia
E6	2	Chthamalus spp.
E6	3	Lithophyllum byssoides
E6	4	Ericaria selaginoides
E6	5	Photophilic algae
E7	1	Lithophyllum byssoides
E7	2	Mediolittoral Ellisolandia elongata
E7	3	Ericaria selaginoides
E7	4	Infralittoral Ellisolandia elongata
E8	1	Verrucaria amphibia
E8	2	Chthamalus spp.
E8	3	Lithophyllum pustulatum
E8	4	Photophilic algae
E9	1	Verrucaria amphibia – Euraphia depressaEuraphia depressa
E9	2	Chthamalus spp.
E9	3	Bangia sp
E9	4	Lithophyllum byssoides
E10	1	Verrucaria amphibia – Euraphia depressaEuraphia depressa
E10	2	Chthamalus spp.
E10	3	Lithophyllum byssoides/lichenoides
E10	4	Mediolittoral Ellisolandia elongata
E10	5	Photophilic algae
E11	1	Chthamalus spp.
E11	2	Lithophyllum incrustans
E11	3	Ericaria selaginoides
E11	4	Photophilic algae
E12	1	Infralittoral Lithophyllum incrustans
E13	1	Infralittoral Lithophyllum incrustans and mesophyllum sp
E14	1	Mediolittoral Ellisolandia elongata
E14	2	Infralittoral Lithophyllum incrustans
E15	1	Verrucaria amphibia – Euraphia depressa
E15	2	Chthamalus spp.
E15	3	lithophyllum incrustans
E15	4	Hildenbrandia sp
E15	5	corrallianales /ulvales/laurencia
E15	6	Gongolaria barbata
E16	1	Verrucaria amphibia – Euraphia depressa
E16	2	Chthamalus spp.
E16	3	litophyllum incrustans
E16	4	Hildenbrandia sp
E16	5	corrallianales /ulvales/laurencia
F1	1	Verrucaria amphibia – Euraphia depressa
F1	2	Chthamalus spp.

Code	N	Community
F1	3	Ralfsia verrucosa
F1	4	Lithophyllum spp
F1	5	Corrallinales
F2	1	Verrucaria amphibia – Euraphia depressa
F2	2	Chthamalus spp.
F2	3	Ralfsia verrucosa
F2	4	Lithophyllum byssoides
F2	5	Mediolittoral Ellisolandia elongata
F3	1	Verrucaria amphibia – Euraphia depressa
F3	2	Chthamalus spp.
F3	3	Ralfsia verrucosa
F3	4	Lithophyllum byssoides
F3	5	Mediolittoral Ellisolandia elongata
F3	6	Ericaria selaginoides
F4	1	Verrucaria amphibia – Euraphia depressa
F4	2	Chthamalus spp.
F4	3	Ralfsia verrucosa
F4	4	Mediolittoral Ellisolandia elongata
F4	5	Ericaria selaginoides
F4	6	Photophilic algae
F5	1	Verrucaria amphibia – Euraphia depressa
F5	2	Chthamalus spp.
F5	3	Ralfsia verrucosa
F5	4	Mediolittoral Ellisolandia elongata
F5	5	Pterocladiella capillacea
F5	6	Photophilic algae
F6	1	Verrucaria amphibia – Euraphia depressa
F6	2	Chthamalus spp.
F6	3	Ralfsia verrucosa
F6	4	Lithophyllum incrustans
F6	5	Photophilic algae
F7	1	Verrucaria amphibia – Euraphia depressa
F7	2	Chthamalus spp.
F7	3	Bangia fuscopurpurea
F7	4	Ralfsia verrucosa
F7	5	Ulvales Infralittoral
F7	6	Infralittoral Ellisolandia elongata
F8	1	Verrucaria amphibia – Euraphia depressa
F8	2	Chthamalus spp.
F8	3	Ralfsia verrucosa
F8	4	Ulvales
F8	5	Mediolittoral Ellisolandia elongata
F8	6	Photophilic algae
F9	1	Verrucaria amphibia – Euraphia depressa
F9	2	Chthamalus spp.
F9	3	Bangia fuscopurpurea
F9	4	Ralfsia verrucosa
F9	5	Ulvales Infralittoral
F9	6	Infralittoral Ellisolandia elongata
F10	1	Verrucaria amphibia – Euraphia depressa
F10	2	Chthamalus spp.
F10	3	Ralfsia sp/litophyllum
F10	4	Photophilic algae
F10	5	Ericaria selaginoides
F10	6	Infralittoral Corrallina elongata
F10	8	Halopteris scoparia

Code	N	Community
F10	9	Infralittoral corallinales
G1	1	Chthamalus spp.
G1	2	Gelidium spp
G1	3	Corallinales
G2	1	Verrucaria amphibia – Euraphia depressa
G2	2	Chthamalus spp.
G2	3	Gelidium spp
G2	4	Corallinales
G2	5	Photophilic algae
G3	1	Verrucaria amphibia – Euraphia depressa
G3	2	Chthamalus spp.
G3	3	Mediolittoral Ellisolandia elongata
G3	4	Ericaria selaginoides
G3	5	Photophilic algae
G4	1	Verrucaria amphibia – Euraphia depressa
G4	2	Chthamalus spp.
G4	3	Mediolittoral Ellisolandia elongata
G4	4	Ericaria selaginoides
G4	5	Photophilic algae
G5	1	Verrucaria amphibia – Euraphia depressa
G5	2	Chthamalus spp.
G5	3	Mediolittoral Ellisolandia elongata
G5	4	Cystoseira spp
G5	5	Photophilic algae
G6	1	Verrucaria amphibia – Euraphia depressa
G6	2	Chthamalus spp.
G6	3	Gelidium spp
G6	4	Hypnea musciformis
G6	5	Infralittoral Ellisolandia elongata
G7	1	Chthamalus spp.
G7	2	Ceramiales
G7	3	Ulvales
G7	4	Infralittoral Ellisolandia elongata
G8	1	Verrucaria amphibia – Euraphia depressa
G8	2	Chthamalus spp.
G8	3	Ulvales
G8	4	Infralittoral Ellisolandia elongata
G9	1	Verrucaria amphibia – Euraphia depressa
G9	2	Chthamalus spp.
G9	3	Infralittoral Ellisolandia elongata
G10	1	Chthamalus spp.
G10	2	Ulvales
G10	3	Mediolittoral Ellisolandia elongata
G10	4	Photophilic algae
G11	1	Verrucaria amphibia – Euraphia depressa
G11	2	Chthamalus spp.
G11	3	Bangia fuscopurpurea
G11	4	Ulvales
G11	5	Gelidium spp
G11	6	Mediolittoral Ellisolandia elongata
G11	7	Photophilic algae
G12	1	Verrucaria amphibia – Euraphia depressa
G12	2	Chthamalus spp.
G12	3	Ceramiales/Osmundea spp.
G12	4	Mediolittoral Ellisolandia elongata
G12	5	Infralittoral Mytilus galloprovincialis

Code	N	Community
G12	6	Infralittoral Ellisolandia elongata
G13	1	Mediolittoral Ellisolandia elongata
G13	2	Ericaria selaginoides
G13	3	Photophilic algae
G14	1	Mediolittoral Ellisolandia elongata
G14	2	Ericaria selaginoides
G14	3	Photophilic algae
G15	1	Mediolittoral Ellisolandia elongata
G15	2	Infralittoral Lithophyllum incrustans
G16	1	Gelidium spp
G16	2	Mediolittoral Ellisolandia elongata
G16	3	Cystoseira compressa
G16	4	Photophilic algae
G17	1	Barren rock
G17	2	Mediolittoral Ellisolandia elongata
G17	3	Infralittoral Ellisolandia elongata
G18	1	Corallinales
G18	2	Cystoserira sedoises
G19	1	Verrucaria amphibia – Euraphia depressa
G19	2	Chthamalus spp.
G19	3	Ulvales
G19	4	Mediolittoral Ellisolandia elongata
G20	1	Corallinales
G20	2	Gongolaria barbata
G21	1	Mediolittoral Ellisolandia elongata
H1	1	Hildenbrandia sprandia sp./Phymatolithon sp.
H1	2	Mediolittoral Ellisolandia elongata
H1	3	Infralittoral Ellisolandia elongata
H2	1	Hildenbrandia sprandia sp./Phymatolithon sp.
H2	2	Mediolittoral Ellisolandia elongata
H2	3	Infralittoral sciaphilic Ellisolandia elongata
H3	1	Bangia fuscopurpurea
H3	2	Red algae
H3	3	Photophilic algae
H4	1	Verrucaria amphibia – Euraphia depressa
H4	2	Chthamalus spp.
H4	3	Bangia fuscopurpurea
H4	4	Ulvales
H4	5	Infralittoral Ellisolandia elongata
I1	1	Ericaria selaginoides
I1	2	Photophilic algae
I2	1	Barren rock
I2	2	Photophilic algae
I2	3	Gongolaria barbata
I3	1	Verrucaria amphibia – Euraphia depressa
I3	2	Chthamalus spp.
I3	3	Enteromorpha sp
I3	4	Gongolaria barbata
I3	5	Halopteris sp
I4	1	Gravel
I4	2	Gongolaria barbata
I5	1	Verrucaria amphibia – Euraphia depressa
I5	2	Chthamalus spp.
I5	3	Cystoseira humilis
I5	4	Photophilic algae
I6	1	Verrucaria amphibia – Euraphia depressa

Code	N	Community
I6	2	Chthamalus spp.
I6	3	Ericaria crinita
I6	4	Photophilic algae
I7	1	Chthamalus spp.
I7	2	Cystoseira compressa
I8	1	Verrucaria amphibia – Euraphia depressa
I8	2	Chthamalus spp.
I8	3	Ericaria selaginoides
I9	1	Verrucaria amphibia – Euraphia depressa
I9	2	Chthamalus spp.
I9	3	Ulvales
I9	4	Ceramiales
I9	5	Hypnea sp
I9	6	Gongolaria barbata
I10	1	Verrucaria amphibia – Euraphia depressa
I10	2	Chthamalus spp.
I10	3	Ericaria crinita
I11	1	Verrucaria amphibia – Euraphia depressa
I11	2	Chthamalus spp.
I11	3	Ulvales
I11	4	Ericaria crinita
I14	1	Verrucaria amphibia – Euraphia depressa
I14	2	Chthamalus spp.
I14	3	Ulvales
I15	1	Verrucaria amphibia – Euraphia depressa
I15	2	Chthamalus spp.
I15	3	Photophilic algae
I16	1	Mediolittoral rock pools with Ulvales
I16	1	Infralittoral Mytilus galloprovincialis
I17	1	Photophilic algae Infralittoral
J1	1	Posidonia oceanica
J2	1	Cymodocea nodosa and Zostera noltii
K1	1	Barren rock
L1	1	Sea urchin overgrazing
M1	1	Freshwater sources Photophilic algae
N1	1	Mediolittoral and infralittoral of Ports et marinas
N2	1	Mediolittoral and infralittoral of artificialized coast
O	1	Soft-bottom

Annex 2 – The benthic habitats found along the coast studied, corresponding to the EUNIS, CORINE and LPRE typologies.

Stage Level	Habitat	Alg-Mar-Hab Code	Lpre Code	Corine Code	Eunis Code
Supralittoral	Cyanobacteria and lichen association	A1.01	01010102		A1.42
Supralittoral	Facies with *Melarhaphe neritoides, Euraphia depressa* and *Chthamalus* spp	A1.02	01010103		A1.161
Supralittoral	Facies with *Verrucaria* sp.	A1.03	01010103	18.16	
Supralittoral	Freshwater spring in supralittoral rock	A1.04	010102	18.18	
Supralittoral	Cuvettes with variable salinity	A1.05	0101102	18.17	A1.42
Supralittoral lower	Facies with *Patella* spp. & *Chthamalus* spp.	A1.06	02010214	18.1311	A1.112
Mediolittoral/ High hydrodynamic	Facies with *Patella* spp. & *Chthamalus* spp	A2.01.01.01	02010214	18.1311	A1.112
Mediolittoral/ High hydrodynamic	Association with *Lithophyllum byssoides* TROTTOIR	A2.01.01.02	02010115	18.132	A1.141
Mediolittoral/ High hydrodynamic	Belt of *Neogoniolithon brassica-florida*	A2.01.01.03	02010226	18.112	A1.134
Mediolittoral/ High hydrodynamic	Association with *Corallina elongata*	A2.01.01.04	02010227	18.111	
Mediolittoral/ High hydrodynamic	Association with *Gellidium* spp	A2.01.01.05	02010311	18.127	A1.233
Mediolittoral/ High hydrodynamic	Association with *Rissoella verruculosa*	A2.01.01.06	02010215	18.1313	A1.133
Mediolittoral/ High hydrodynamic	Facies with *Bangia atropurpurea*	A2.01.01.07	02010220	18.1316	A1.131
Mediolittoral/ High hydrodynamic	Facies with *Mytilus galloprovincialis*	A2.01.01.08	02010224	18.113	
Mediolittoral/ High hydrodynamic	Association with Ceramiales	A2.01.01.09	0201011202	18.125	
Mediolittoral/ High hydrodynamic	Facies with vermets *Dendropoma lebeche*	A2.01.01.10	02010226	18.112	
Mediolittoral/ Moderate hydrodynamic	Facies with photophilic red algae	A2.01.02.01			A1.12
Mediolittoral/ Moderate hydrodynamic	Association with *Polysiphonia* spp	A2.01.02.02	02010219	18.1315	
Mediolittoral/ Moderate hydrodynamic	Association with *Padina pavonica* et *Halopteris scoparia*	A2.01.02.03	0201021303		
Mediolittoral/ Moderate hydrodynamic	Association with *Ralfsia verrucosa*	A2.01.02.04	02010216	18.1314	
Mediolittoral/ Moderate hydrodynamic	Facies with *Rissoela verruculosa*	A2.01.02.05	02010215	18.1313	A1.133
Mediolittoral/ Moderate hydrodynamic	Facies with *Lithophyllum papillosum*	A2.01.02.06	02010226	18.112	
Mediolittoral/ Moderate hydrodynamic	Facies with *Lithophyllum byssoides*	A2.01.02.07	02010115	18.132	A1.141
Mediolittoral/ Moderate hydrodynamic	Facies with *Corallina elongata*	A2.01.02.08	02010227	18.111	
Mediolittoral/hy Moderate hydrodynamic	Facies with *Ulva rigida*	A2.01.02.09	0201231	18.126	A1.341

Stage Level	Habitat	Alg-Mar-Hab Code	Lpre Code	Corine Code	Eunis Code
Mediolittoral/ Moderate hydrodynamic	Facies with Vermets *Dendropoma lebeche*	A2.01.02.10	02010226	18.112	
Mediolittoral/ Moderate hydrodynamic	Facies with *Hypnea* sp	A2.01.02.11	02010235	18.111	
Mediolittoral/Sheltered	Belt with *Nemoderma* sp	A2.01.03.01	02010308	18.122	
Mediolittoral/Sheltered	Association with *Lithophyllum incrustans*	A2.01.03.02	02010309	18.124	
Mediolittoral cave	Mediolittoral caves with *Lithophyllum byssoides*	A2.01.04.01.	02010225	18.121	A1.141
Mediolittoral cave	Mediolittoral caves with *Hildenbrandia rubra et Phymatolithon lenormandii*	A2.01.04.02.	02010404	18.14	A1.44B
Mediolittoral cave	Mediolittoral caves with *Lithophyllum* spp	A2.01.04.03.	02010309	18.124	
Mediolittoral cave	Mediolittoral caves with *Actinia equina* et *Astroides calycularis*	A2.01.04.04.			
Mediolittoral cave	Mediolittoral caves with *Actinia equina*	A2.01.04.05.			
Mediolittoral basins	Encrusting algae and sea urchins	A2.01.05.01	02010404	18.15	
Mediolittoral basins	Association with *Cystoseira* spp	A2.01.05.02	02010405	18.16	
Mediolittoral basins	Association with vermets	A2.01.05.03	02010406	18.17	
Mediolittoral basins	Association with Ulvales	A2.01.05.04	02010407	18.18	
Mediolittoral basins	Association with Dictyotales	A2.01.05.05	02010408	18.19	
Mediolittoral basins	Association with *Codium* spp	A2.01.05.06	02010409	18.20	
Upper infralittoral	Association with *Ericaria selaginoides*	A3.01.01.01	0301022101	11.2411	
Upper infralittoral	Association with *Sargassum vulgare*	A3.01.01.02	0301030511		
Upper infralittoral	Association with *Sargassum spp*	A3.01.01.03	0301011702		
Upper infralittoral	Association with *Cystoseira barbata/Cystoseira foeniculacea*	A3.01.01.04	0301030601		
Upper infralittoral	Association with *Cystoseira compressa*	A3.01.01.05	0301030508		
Upper infralittoral	Fucales forests	A3.01.01.06	03010116		
Upper infralittoral	Association with *Ericaria crinita*	A3.01.01.07	0301030501	11.24131	
Upper infralittoral	Association with *Cystoseira sedoides*	A3.01.01.08			
Upper infralittoral	Facies with Dictyotales	A3.01.01.09	0301021603		
Upper infralittoral	Association with *Padina pavonica*	A3.01.01.10	0301021701		
Upper infralittoral	Association with *Dictyopteris polypodioides, Zonaria tournefortii*	A3.01.01.11	0301021601		
Upper infralittoral	Association with *Halopteris scoparia*	A3.01.01.12	0301030705	11.24141	A3.331
Upper infralittoral	Photophilic algae in the absence of fucales	A3.01.01.13	0301030705	11.24141	A3.331

Stage Level	Habitat	Alg-Mar-Hab Code	Lpre Code	Corine Code	Eunis Code
Upper infralittoral	Association with *Codium* spp	A3.01.01.14	03010218		
Upper infralittoral	Association with *Colpomenia sinuosa*	A3.01.01.15	0301030711		
Upper infralittoral	Association with *Ulva* spp	A3.01.01.16			
Upper infralittoral	Facies with *Mytilus* spp	A3.01.01.17	03010502		
Upper infralittoral	Facies a *Plocamium cartilagineum*	A3.01.01.18	0301022301	11.24182	
Upper infralittoral	Association with *Pterocladiella capillacea*	A3.01.01.19	0301022303	11.24183	A3.334
Upper infralittoral	Association with *Corallina elongata* et algues photophiles	A3.01.01.20	0301022202	11.24121	A3.135
Upper infralittoral	Association with *Corallina elongata*	A3.01.01.21	0301022302	11.24182	
Upper infralittoral	Overgrazed facies with encrusting calcareous algae and sea urchins	A3.01.01.22	03010115		A3.131
Upper infralittoral	Facies with *Lithophylum incrustans*	A3.01.01.23	0301030901	11.24142	A3.131
Upper infralittoral	Association with *Lithophyllum* spp. and *Mesophyllum* spp	A3.01.01.24	03010114		
Upper infralittoral	Facies with *Asparagopsis armata/Taxiformis*	A3.01.01.25	0301022205		
Upper infralittoral	Facies with *Grateloupia lanceola*	A3.01.01.26	0301021401		
Upper infralittoral	Sciaphilic algae	A3.01.01.27	03010411		
Roche artificielle	Managed coastline (decimetric blocks)	A4.01			J4.5
Roche artificielle	Ports and marinas coast	A4.02	070108	89.11	J4.5
Seagrass meadows	*Posidonia oceanica* meadow	A5.01	030512	11.34	A5.535
Seagrass meadows	*Zostera noltii* meadow	A5.02	0305130105		
Seagrass meadows	*Cymodoceae nodosa* meadow	A5.03	0305130104	11.331	A5.53132
Seagrass meadows	*Posidonia oceanica* death mattes	A5.04	03051203	16.1123	A2.13

THE EX-SITU ADAPTATIVE POWER OF THE BLUE CRAB *CALLINECTES SAPIDUS* RATHBUN, 1896

Farida Becir, Asma Leulmi, Malek-Zakia Nessaifia, Samia Bouanani, Mostapha Beniddir

Abstract: In 2023, this study was conducted involving the capture of 115 blue crab (*Callinectes sapidus* Rathbun, 1896) specimens from the Mellah Lagoon, Ramsar site. The crabs were transported alive in clean containers to holding tanks to assess their adaptive capacity and to determine the optimal conditions for their survival.
Known by the nickname 'Dhaech', in the northwest of Africa, for its destructive nature, the blue crab consumes everything in its path, severely disrupting the environmental balance. Since 2019, this invasive species has posed a significant threat to the ecological equilibrium of the Mellah Lagoon. Despite its destructive impact, the blue crab is edible and offers economic potential for the local economy. Its shell contains chitin, a valuable material with multiple uses, including cosmetics, burn treatments, and the production of surgical sutures due to its strength and flexibility. Chitin is also used in wastewater filtration and has applications in the food industry, such as in juice production.
This study presents a solution to mitigate the impact of this destructive invasion on the lake while taking advantage of its economic potential. The approach involves extensive fishing followed by keeping crabs alive until they can be sold on the market. Therefore, we aimed to extend the crabs' survival time in ex-situ conditions for as long as possible.
Our findings show that blue crabs adapt more effectively to brackish water environments compared to freshwater. Notably, the population of crabs caught in the Mellah lagoon also demonstrates the ability to adapt ex-situ to a broad range of physical-chemical conditions, mirroring their adaptability in their natural habitat. The sardine was the best food in terms of cost and yield compared to shrimp and Fish meal. No parasitic forms were detected in the Callinectes sapidus specimens collected from the Mellah lagoon.

Keywords: *Callinectes sapidus*, blue crab, Mellah lake, ex-situ, adaptation

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Introduction

The Mellah Delta is home to various species, including Salicornia and Juncus, as well as a rich diversity of phytoplankton and zooplankton. It also serves as a nursery and feeding ground for many fish species, particularly eels preparing for their long migratory journeys. The lake supports an abundant population of fish such as sea bass, common sole, slap, marbled fish, and eels. Due to the abundance of food, the lake attracts numerous bird species, amphibians, and reptiles. It hosts a variety of waterfowl, including 14 migratory species, 10 breeding species, and 20 wintering species, such as the great cormorant, great crested grebe, and Eurasian eagle-owl. This ecological richness has earned it a place on the Ramsar list of wetlands of international importance.

Callinectes sapidus, commonly known as the blue crab, is native of the western Atlantic Ocean. It has been introduced into the eastern Atlantic, the northern and eastern Mediterranean, Japan, the French Mediterranean lagoons, and the Ebro Delta in Spain, where it is considered an invasive species [3-4]. In Algeria, the blue crab was officially reported on August 26, 2018, in Jijel and later observed in El-Kala (El-Taref department) on November 19, 2019, at Oued Mafragh, and in Mellah Lake [5-7].

The ecology of blue crabs varies by size: larger crabs can inhabit depths ranging from 0 to -35 meters and even as deep as -90 meters, while smaller crabs are typically found in deeper waters [1]. They thrive in temperatures between 3 °C and 35 °C and can survive up to 45 °C for short periods [2]. Although primarily a coastal species, blue crabs are also found in freshwater environments, lakes, estuaries, and mangrove forests [8-9].

Blue crabs, a newly introduced exotic species in Mellah Lake, consume everything in their path, disrupting and impoverishing the local ecosystem. This study proposes an alternative approach to managing this invasion by leveraging the economic potential of the species. The objective of the study is to explore the feasibility of cultivating blue crabs in Mellah Lake and maintaining them alive in controlled conditions. To achieve success in ex-situ cultivation, it is crucial to find the right balance between food quality, population density, and water quality. This balance will help reduce intraspecific competition for food and reproduction, as well as interspecific interactions, such as parasitism, thus significantly lowering the primary causes of mortality.

Materials and Methods

The study was carried out at El-Kala National Park. In 2023, a total of 115 blue crab specimens were gradually caught from Lake Mellah, a brackish lagoon connected to the sea by a 900-meter-long canal. Designated as a Ramsar site on December 12, 2004, Lake Mellah spans nearly 5600 hectares and is situated in El-Kala National Park at coordinates 36° 53' N, 08° 20' E, in the far northeast of Algeria (El Tarf department) [8].

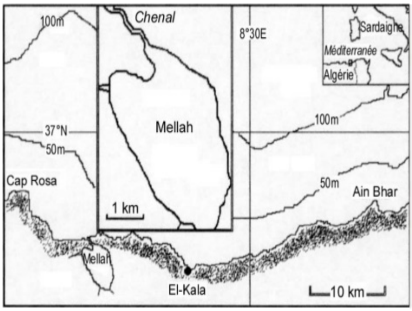

Figure 1 – Location of the Mellah lagoon [10] (left) and a partial view of Mellah Lake (right).

This study was conducted in two phases:

i. At Mellah Lagoon, where:

- 115 specimens of *Callinectes sapidus* were caught, with fish traps,
- With the U-50 multiparameter analyser from HORIBA, we were able to simultaneously measure 11 key water parameters of the Mellah lagoon (Fig. 2),
- Crab measurements (weight, length, and width) were taken (using a calliper and a precision scale), and the sex ratio was calculated.

ii. At the aquaculture farm, where:

- The crabs were kept alive in ex-situ, and their behaviour was monitored.

Since the invasion of El-Kala National Park by the blue crab (Callinectes sapidus) in 2019, its populations have successfully stabilized in wadis, coastal waters, and most notably in Lake Mellah, thriving in both freshwater and brackish environments. After analysing the physical-chemical variations across the different habitats affected in the region, we opted to establish four types of tanks for ex-situ experiments, and we gradually increased crab density and observed their behaviour. The basins were set up as follows:

- Freshwater (tap water) without sand,
- Freshwater (tap water) with sand,
- Brackish (sea water) without sand,
- Brackish (sea water) with sand.

The purpose of this study is to achieve two main objectives related to crab farming. Each of these steps is crucial for the success and sustainability of our aquaculture project. The aims are as follows:

Ensure the survival of crabs

i- Maintain a clean and stable aquatic environment: control parameters such as temperature (20 °C÷25 °C), pH (7÷8), salinity (25 ÷ 32 psu), and a good oxygenation.

ii- Provide a balanced diet: ensure the diet is adapted to the nutritional needs of crabs to promote their health and growth.
iii- Create a suitable habitat: develop a habitat that mimics their natural conditions, allowing crabs to behave naturally and reducing stress.

Successfully fatten the crabs

i. Crab feeding: Three different types of feed were tested to identify the most suitable and cost-effective option (non-GMO fish feed, shrimp, and sardines).
ii. Population density: The number of males and females in each tank was gradually increased to determine the minimum territorial size and ideal sex ratio. The sex ratio represents the proportion between the number of males and females in the population. The territory size refers to the minimum area in which each male establishes its personal space (with reduced interaction, indicated in crabs by a decrease in agitation).
Sex ratio = Number of females / Number of males.
Territory size = Total area of the habitat / Number of males ; under conditions of ecological equilibrium (absence of stress).
iii. Continuous monitoring: The crabs' ex-situ behaviour was continuously observed, including aspects such as feeding patterns, activity levels, and territorial boundaries.

Figure 2 – Ways to catch blue crabs in Lake Mellah.

The crabs were shipped alive in tanks offering the best conditions to aquaculture ponds located 30 km from an aquaculture station. The ponds were already prepared before receiving the harvested crabs.

Figure 3 – Aquaculture ponds.

Results and Discussion

Crab biometry

The easiest way to determine a crab's gender is by examining its abdomen. Males have a more prominent 'T'-shaped abdomen, while females have a triangular abdomen that becomes more pronounced and semi-circular after maturity. The average length of crabs from Lake Mellah is 138.29 mm, with a width of 64.52 mm and a weight of 153.89 g. In terms of size, male blue crabs are consistently larger than female blue crabs, a characteristic clearly observed in the population of Lake Mellah.

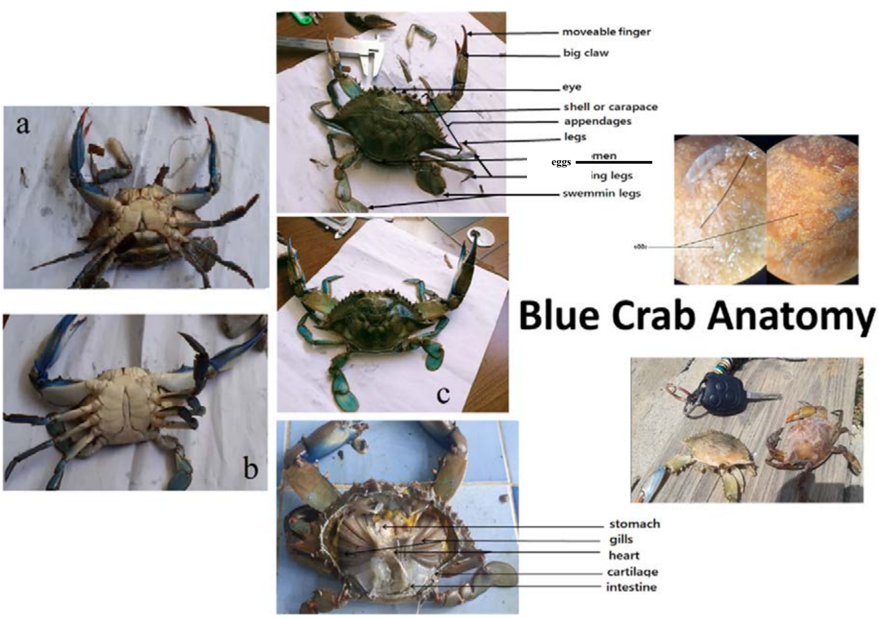

Figure 3 – Lake Mellah's *Callinectes sapidus* population and its anatomy.

The measurements of crabs from Lake Mellah are similar to those of their counterparts sampled in other regions. The species has adapted well after three years of settlement. Our study also revealed that female blue crabs outnumber males at Lake Mellah, with a consistent ratio of four females to every male throughout the year.

Table 1 – Crab measurements.

		Length (mm)	Width (mm)	Weight (g)
Male	Average	144,74	71,76	200,68
	Max	176,26	79,73	292
	Min	127,02	64,6	117,5
Female	Average	136,01	61,96	134,61
	Max	168,62	72,73	189,5
	Min	119,28	10,96	83,5

➢ ***Feeding Trials:*** this study assessed three types of feed to identify the most effective and cost-efficient option for sustaining blue crabs (Callinectes sapidus):

- Fish Meal (Natural, Non-GMO): This feed showed limited effectiveness, as it did not sufficiently attract the crabs or satisfy their feeding needs, resulting in low consumption rates,
- Rose Shrimp: Known to be a highly preferred food source, particularly during the reproductive season, pink shrimp were readily consumed by the crabs. However, their introduction led to increased aggression and agitation among males, which resulted in physical injuries such as shell fractures, loss of body mass, and in some cases, mortality.
- Sardines: Sardines, a locally abundant and nutritionally rich resource, proved to be a more favourable option. They provided high nutritional value at a reasonable cost, making them a sustainable choice for feeding.

Feeding was replenished in each basin as needed, allowing for continuous observation and calculation of the average daily intake per crab. This approach enabled precise monitoring of feeding behaviour and consumption rates, ensuring an optimal feeding regime.

Table 1 – Crab's feeding

Food	Consumed portion	Quantity/crab/day
Fish Meal	-	-
Rose Shrimp	the abdomen	3 ± 1
Sardines	trunk and tail	0,1

Sardines were unanimously identified as the most effective feed tested. However, if not consumed promptly, it contributes to increased water turbidity, necessitating water replacement every two to three days. The farm's proximity to the sea, located approximately 100 meters away, facilitates efficient water renewal.

- ***Habitat selection:*** Initially, tanks were filled only with water, two tanks with freshwater and two with seawater. In the freshwater tanks, the crabs exhibited frequent agitation, and their food consumption was consistently two to three times higher than in the seawater tanks. In the seawater tanks, the crabs became agitated in our presence, leading us to suspect that the species exhibits shy behaviour. To simulate the lakebed environment, we added sand (collected from the lake) to one seawater tank and one freshwater tank, covering the tank bottoms. The addition of sand significantly reduced agitation, with 100 % of the crabs burying themselves in the sand. As a result, all crabs became immobile, and their food consumption dropped to nearly zero at temperatures ranging between 17 °C and 20 °C. No crab mortality was recorded under these conditions over the course of four months.

- ***Couple formation*****:** at aquaculture ponds the sex ratio balance is four to five females for each male. The imbalance causes a strong agitation of males and a lot of aggressiveness that can cause even the death of the less competitive one. The male even outside the laying period spends his days protecting its females by standing on these last and attacking all those who come close to it. However, no ovigerous females were observed during the breeding period.

- ***Mortality*****:** the main cause of crab mortality in ex situ was intraspecific interactions for territory and/or female protection and/or foraging. We were able to determine the mean area of occupancy of an ex-situ male crab by analysing its behaviour, which showed an average surface area of 0.4 m^2. This minimum average surface area ensures population stability, minimizing crab losses to nearly zero and eliminating any signs of agitation.

- ***Parasitism:*** during this study, we recorded the loss of five crabs (one male and four females). According to the literature, parasitism is a major cause of mortality in *Callinectes sapidus*. The deceased specimens, and more than 30 additional dead crabs collected from the lake, were examined at the university laboratory using to identify any potential parasites. The trematode (*Spelotrema nicolli*) is the parasite known to infect *Callinectes sapidus* [11-12]. In the laboratory, crabs were first inspected with the naked eye to detect macro-parasites, followed by detailed examination under the binocular microscope for internal micro-parasites. No signs of parasitism were found in any of the examined specimens.

Conclusion

The blue crab (*Callinectes sapidus* RATHBUN, 1896) was native of the temperate and tropical coasts of the western Atlantic. Known for its remarkable adaptability [13], this species has successfully established itself in its new biogeographical range, the Mellah Lagoon. This environment was stabilized by the lake's physical-chemical and biological conditions [14], and the morphometric characteristics of crabs from Mellah remain consistent with those observed in other populations.

The ex-situ maintenance of live blue crabs was successfully achieved at the aquaculture facility using seawater tanks with sand bottoms, maintained at temperatures between 17 °C and 20 °C. The operational costs were limited to seawater transportation, electricity to run the structure, and food supplies. During winter, blue crabs naturally reduce their activity and food intake, a behaviour also observed in the aquaculture environment, where the crabs move only when absolutely necessary.

Males establish territorial boundaries and protect their mates by covering the females with their bodies. Each male tends to guard a group of four to five females, shielding them from potential threats.

Increased agitation among crabs in the tanks is associated with heightened mobility and aggression, which may be triggered by insufficient space (less than 0.4 m^2 per crab), competition for food, or perceived dangers.

Parasitological analysis revealed no signs of parasitism, suggesting that the crabs in this population are free from parasitic infection.

While this invasive species disrupts the ecological balance of Lake Mellah, a Ramsar Site, it is highly valued and appreciated in other regions. There is an urgent need to stabilize the species' presence and transform it into a sustainable economic resource. This study demonstrates the feasibility of this approach at a low cost, where the commercialization of the species could offset the expenses of restoring the invaded areas.

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MONITORING AND ASSESSMENT OF THE ENVIRONMENTAL QUALITY OF TRANSITIONAL WATERS IN SICILY (ITALY)

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Abstract: Transitional waters represent high valuable wetlands characterized by extremely dynamic processes and irregular temporal trends. These coastal areas are vulnerable interface systems sensitive to natural and human pressures that cause a continuous environmental degradation and a consequential unbalance of the natural ecosystem. Monitoring plays a key role in the management of these ecosystems in order to prevent further deterioration and enhance the status of environmental quality. This paper aims to evaluate the ecological and chemical status of five Sicilian transitional waters systems (Oliveri-Tindari, Cape Peloro, Vendicari, Longarini-Cuba and Marsala) over a 3-year monitoring cycle according to the Water Framework Directive (WFD, 2000/60/EC). The water quality exhibited negative evidences since no water body monitored achieved the overall good environmental status assessed by different biological and chemical elements.

Keywords: WFD, transitional waters, environmental status, water quality, Sicily

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Giancarlo Bellissimo, Francesca Galfo, Paolo Balistreri, Benedetto Sirchia, *Monitoring and assessment of the environmental quality of transitional waters in Sicily (Italy)*, pp. 48-68, DOI: 10.36253/979-12-215-0556-6.04

Introduction

Transitional waters, hereafter TWs, include all types of water bodies (WBs) which are brackish or hyperhaline at the boundary between terrestrial/freshwater and marine/coastal systems [4]. TWs are recognized as very complex systems characterized by weak hydrodynamics, shallow depth, limited size and high potential biodiversity around which numerous human activities revolve. Almost all of these ecosystems are subject to protection by several international conventions (e.g., Ramsar Convention) and directives (e.g., EU Birds Directive 2009/147/EC) and they are encoded as priority habitat type for conservation (1150 *Coastal lagoons*) under the EU Habitats Directive (92/43/EEC) because of their notable naturalistic value and ecological importance.

The European Water Framework Directive (WFD, 2000/60/EC) legally defines TWs the "bodies of surface water in the vicinity of river mouths which are partly saline in character as a result of their proximity to coastal waters but which are substantially influenced by freshwater flows" [10]. In the context of the WFD only five typologies of TWs are reported: delta, estuaries, lagoons, brackish lakes and coastal ponds. The WFD requires monitoring and assessment of the Ecological Status (ES) and Chemical Status (CS) in order to evaluate the Environmental Quality (EQ) of TWs. In accordance with the WFD, the ES is an expression of the quality of the structure and functioning of aquatic ecosystems associated with surface waters. In Italy, the ES is assessed using four Biological Quality Elements (BQEs, phytoplankton, macrophytes, benthic macroinvertebrates and fish faunal) and related indices that are adopted by the national law (MD 260/2010 and subsequent modifications and integration) in agreement with the WFD requirements. In particular, MPI (Multiparametric Phytoplankton Index), MAQI (Macrophyte Quality Index), M-AMBI (Multivariate-Azti Marine Biotic Index) and HFBI (Habitat Fish Bioindicator) are being regularly applying as monitoring tools for the Regional Agencies to assess the ecological quality of TWs [12]. Parallel, the WFD establishes the use of Supporting Quality Elements (SQEs) identified as chemical, physical-chemical and hydro-morphological quality elements that contribute to the ES classification, confirming or not the classification provided by the BQEs. The classification of a WB is based on the "one out-all out" principle, proposed by the WFD [9], meaning that the worst quality of any of the BQEs used in the assessment is sufficient to downgrade all of them. The ES provides a composite assessment in five quality classes, from High to Bad, based on the conditions of several BQEs and their deviation from a referenced WB.

The CS is determined via the monitoring of the priority substances in two matrices (water and sediment) established in the Environmental Quality Standards (EQSs) Directive 2008/105/EC (as amended by the Priority Substances Directive 2013/39/EU), transposed into the Italian legal system by LD 172/2015 (Table 1A and Table 2A). EQSs are limits on the concentration, expressed as maximum allowable concentration (MAC) and annual average (AA) of a chemical pollutant that must never be exceeded. The CS is represented by two quality classes (Good and Not Good) based on compliance with EQSs. The good CS is achieved when no concentrations of one or more priority substances exceed agreed standards. Finally, the environmental quality (EQ) is determined combining the ES with the CS: the worst class quality of either one regulates the overall status. In particular, the good EQ is reached when the CS is good, and the ES is in at least a good status.

In Italy, TWs are divided according to MD 131/2008 into typologies identified on the basis of their geomorphology (coastal lagoons or river mouths), tidal range (>50 cm or <50 cm), total surface of the WB (>2.5 km^2 or between 0.5 km^2 and 2.5 km^2) and, finally, salinity (oligohaline <5 PSU; mesohaline between 5 PSU and 20 PSU; polyhaline between 20 PSU and 30 PSU; euhaline between 30 PSU and 40 PSU; hyperhaline >40 PSU). For the purposes of the classification under the WFD, three macrotypes of TWs have been defined according to the tidal and salinity (divided into two types: less than 30 PSU; greater than 30 PSU) range variation: two macrotypes for tidal systems and one macrotype for non-tidal systems (MD 260/2010 - Table 4.4/a).

In Sicily, TWs include brackish lakes, coastal ponds, lagoon-like coastal basins, mires, swamps and saltworks but only a few areas fall within the WFD-compliant monitoring requirements. Accordingly, in 2016 the last Management Plan of the Hydrographic District of Sicily selected five significant TWs systems (including thirteen WBs) in the framework of the institutional activities for the implementation of the Italian national legislation (LD 152/06) that acknowledges the WFD [3]. Here, we present the results of a 3-year monitoring cycle (2020-2022) in order to provide an update of the data and obtain the current evaluation of EQ of five Sicilian TWs systems.

Materials and Methods

All TWs systems monitored in this study (Fig. 1) fall into different protection regimes (e.g., Natural Oriented Reserves, Sites of Community Importance, Special Protection Zones, Important Bird Areas and International Important Wet Zones). They include non-tidal ecosystems of different typology from a geomorphological point of view and salinity (Table 1). In particular, two TWs systems fall within the WFD typologies (Oliveri-Tindari and Cape Peloro), while three are listed under typologies not included in the WFD. Specifically, the four WBs of Oliveri-Tindari (Marinello, Mergolo della Tonnara, hereafter Mergolo, Porto Vecchio and Verde) and the two WBs of Cape Peloro (Ganzirri and Faro) can be classified as coastal ponds and brackish lakes, respectively. The three WBs of Vendicari area (Piccolo, Grande and Roveto) can be classified as mires while the Longarini-Cuba wetland-complex ones (Cuba, Longarini 1 and Longarini 2) as swamp lakes. Stagnone di Marsala, hereafter Stagnone, represents the largest lagoon of Sicily characterized by hydrodynamic exchange with the adjacent open sea and it can be defined as a lagoon-like coastal basin. Their detailed description in terms of ecological and environmental features is given by [5, 11, 13]. However, according to the last Sicilian Management Plan, all thirteen WBs within the five transitional systems belong to the only typology “coastal lagoon”, defined macrotype M-AT-1 *sensu* MD 260/2010, with a dimension lower than 2.5 km^2 with the exception of the Stagnone (about 20 km^2). A variable number of stations (1 or 2) for each WB was sampled in accordance with [12]. Due to the larger spatial extension of the Stagnone, six stations in three areas (northern, central and southern) were selected. At all stations, surface water samples were collected monthly in each year and analysed for determination of priority substances (LD 172/2015 - Table 1/A). Physical-chemical parameters such as pH, temperature, salinity and dissolved oxygen were also obtained monthly by a multiparameter probe (Aquaread AM-200). Additional water samples were collected quarterly in each year for quantifying non-priority chemical substances (LD 172/2015 - Table 1B), phytoplankton, chlorophyll-*a* (Chl-*a*) and dissolved nutrients. The latters, including nitrogen as ammonium (N-NH_3), nitrites (N-NO_2) and nitrates (N-NO_3), summed and reported as dissolved inorganic nitrogen (DIN) and reactive phosphorus as orthophosphates (P-PO_4) were considered as representatives of the physical-chemical quality elements to support BQEs classification. According to MD 260/2010, thresholds for DIN are defined for two different salinity typologies: <30 PSU, including oligohaline, mesohaline and polyhaline WBs (threshold = 30 μM); >30 PSU, including euhaline and hyperhaline WBs (threshold = 18 μM). Currently, the threshold for P-PO_4 is set only for WBs with salinity >30 (threshold = 0.48 μM). The frequency of macrophyte and benthic macroinvertebrates monitoring was two seasonal samples (spring and autumn) in only one year over the studied period. Fish faunal was collected but it was not taken into account in the ES evaluation. A sediment sample was collected and analysed for quantifying priority and non-priority chemical substances (LD 172/2015 - Table 2/A and Table 3/B) from each WB in only one year over the studied period. Field and laboratory activities were performed according to the national protocol [12].

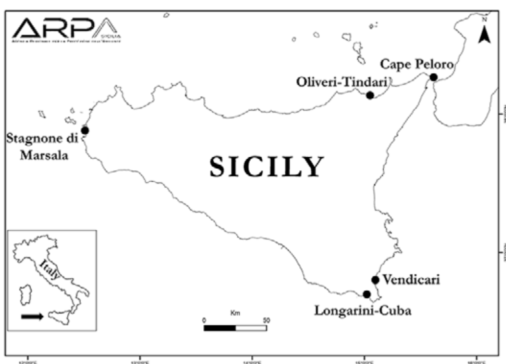

Figure 1 – The five Sicilian TWs systems monitored in this study.

Results

The monitored TWs systems cover all salinity classes, with a prevalence of eu-hyperhaline WBs (eight out the thirteen) and oligo-mesohaline (four out the thirteen), while only one WB was polyhaline (Table 1). The annual mean physical-chemical parameters of the water column are reported in Table 2. Among the supporting physical-chemical elements required for confirming the ES classification (Table 3), DIN concentrations exceeded the good/moderate threshold (i.e., in moderate status) set in MD 260/2010 (Table 4.4.2/a) in six out the thirteen WBs (Marinello, Ganzirri, Piccolo, Grande, Longarini 1, and Cuba); the remaining seven WBs resulted below the good/moderate threshold (i.e., in good status). In particular, the NO_3 ions were predominant within the dissolved inorganic N ($DIN=NH_4+NO_2+NO_3$) pool of all the examined WBs. The annual mean concentrations of DIN (range 0.47÷113.26 µM) resulted beyond the threshold in Cuba, Longarini 1, Piccolo and Grande (the latter with values up to 6 times higher than the threshold). Marinello and Ganzirri showed the highest DIN concentrations in Oliveri-Tindari and in Cape Peloro, respectively. Differently, Stagnone was a nutrient-poor area referring to the lowest values of DIN detected in all three areas. The annual mean concentrations of $P\text{-}PO_4$ (range 0.02÷0.28 µM) resulted below the threshold in all WBs with the highest values in Longarini 2. The Chl-*a* mean concentration in all WBs showed a trophic gradient varying from oligotrophic (0.23±0.16 $\mu g l^{-1}$ in southern Stagnone) to hypertrophic (55.67±106.74 $\mu g l^{-1}$ in Ganzirri). Peak values of 47.87 and 311.87 $\mu g l^{-1}$ were recorded in summer months in Roveto and in Ganzirri, respectively. Within the supporting chemical elements, non-priority substances analysed in all WBs resulted under the settled thresholds of MD 260/2010 (Table 4.5/a).

Four priority substances were found to be exceed the EQSs in eight WBs (Mergolo, Porto Vecchio, Faro, Grande, Longarini 1, Longarini 2, Cuba, and Stagnone). Particularly, mercury was detected only in water in seven out the thirteen WBs with values about 4 times higher than MAC-EQS in Mergolo and Longarini 1 (Table 4). In addition, lead occurred only in sediment in all three WBs of the Longarini-Cuba complex with values 4.5 times higher than AA-EQS in Longarini 2. DDE [2.4+4.4] was found in sediment in Longarini 2 and Cuba with values 2.5 and 2 times higher than AA-EQS, respectively. Lastly, tributyltin was found in sediment only in Stagnone with values up to 2.5 times higher than AA-EQS (Table 4). Hence, eight out the thirteen WBs were classified as "Not Good" (Mergolo, Porto Vecchio, Faro, Grande, Longarini 1, Longarini 2, Cuba and Stagnone) (Table 5).

Regarding the ES, nine out the thirteen WBs were classified as "Bad" and "Poor" (Marinello, Mergolo, Porto Vecchio, Verde, Grande, Roveto, and all WBs of the Longarini-Cuba complex), three as "Moderate" (Piccolo, Faro and Ganzirri) and one as "Good" (Stagnone). Finally, the overall EQ is resulted "Not Good" in all WBs (Table 5).

Discussion

No WB of the Sicilian TWs achieved the good environmental quality. The target set by the WFD, that all TWs should be in at least a good status by 2021 in its second management cycle, was therefore missed by a wide margin. Among the thirteen WBs monitored, the failure of the WFD goal is related to the CS and ES classification in eight and in five WBs, respectively. Specifically, the missing target was determined in seven WBs by both the ES and CS, in five WBs exclusively by the ES and in only one WB by the CS. These results state that the assessment of water quality was particularly critical because Sicilian TWs systems support both extreme fluctuations in environmental variables (e.g., salinity, temperature, dissolved oxygen, exchanges with the sea, and meteorological conditions) and anthropic activities that influence directly and indirectly the biological communities, making these ecosystems high spatially and temporally heterogenous. Organic matter, depth, and salinity have been reported to be among the environmental variables that significantly affect spatial distribution of BQEs [7]. Moreover, the latters can be either sensitive to natural stressors and at the same time to increasing concentrations of nutrients or chemical substances making it difficult to distinguish a naturally stressed habitat from an anthropogenically stressed one. The cases of Oliveri-Tindari and Vendicari are emblematic. In spite of the pristine character of the areas, which are far from urban centres and are characterized by very low anthropogenic impact, the resulting ES is mainly driven by the low M-AMBI index values. This outcome can be explained by the fact that these areas are easily subject to dystrophic crises until reaching complete anoxia with the production of hydrogen sulfide and widespread deaths of species in all habitats present. Generally, this happens as a synergistic effect of a set of conditions, which occur during the summer season and in basins with shallow depths, such as high temperatures and water stagnation due to poor water exchange. Particularly, in some WBs it was not possible to apply the M-AMBI index since no benthic macroinvertebrates were detected. For instance, in Grande the community is likely to not have established over the monitored period, as this WB has a water supply linked to meteoric contributions and infiltrations of seawaters via a ducting system, up to dry up in the summer period. In Piccolo, the number of species detected was not suitable for the application of the index. The only species found was the gastropod *Pirenella conica* (Blainville, 1829) reported in the literature in a salinity range from 15-90 to 280 PSU [14]. Due to its wide tolerability range, it could be the only species to be present in the periods in which the two samplings were carried out in this WB which it is fed by a spring of freshwater and by the contribution of atmospheric precipitations. Similarly, low M-AMBI index values were recorded in the Longarini-Cuba complex. This transitional system is subject to natural stresses comparable to those of Oliveri-Tindari and Vendicari; however, this area is also influenced by pollution from diffuse sources (e.g. intensive agriculture, contaminated or abandoned industrial sites) as highlighted by the analysis of pressures and impacts of the last Sicilian Managment Plan. The presence of large quantities of toxic agricultural chemicals and artificial fertilisers together with illegal garbage dumps are likely to explain both DDE [2.4+4.4] and lead concentrations beyond the AA-EQS. In addition, the presence of these two chemical contaminants could have a direct impact on benthic communities. Macroinvertebrates are sensitive to an enrichment of organic substance and chemical pollution in water and sediment deriving from activities mainly linked to intensive and widespread agriculture [15]. The latter togheter with surface runoff of urban areas can determine nutrient enrichment altering the water quality and, therefore, an increase in the frequency and intensity of algal blooms, especially in the summer months. This fact was likely to cause the low MPI index values in Grande and Ganzirri where significant blooms of phytoplankton, validated by higher chlorophyll-*a* and DIN concentrations, were recorded. On the contrary, all WBs resulted above the MaQI moderate status with the exception of Mergolo where no sensitive macroalgal species, *sensu* MAQI, was detected, indicating a negligible probability of alteration of the functioning or the structure of the ecosystem due to nutrient enrichment [6]. The good or high macrophyte ecological status was related to both the presence and high cover values of the seagrass *Cymodocea nodosa* (Ucria) Ascherson, in Porto Vecchio, Ganzirri and Stagnone, while the aquatic angiosperm *Ruppia maritima* Linnaeus contributed on its own to the good or high MaQI status in some WBs of Vendicari and Longarini-Cuba complex. Stagnone was the only WB exhibiting a good/high class of all biotic indeces confirming the previous ecological quality evaluation [3, 8]. However, according to "one out-all out" approach, this WB resulted in not good environmental status, because of the exceeding of AA-EQS for tributyltin (TBT), a class of organotin compounds widely used as a biocide in anti-fouling paints [2]. A similar outcome was recorded in seven WBs showing concentrations beyond the MAC-EQS for mercury that it is considered as one of the most serious contaminants entering the marine environment through a variety of sources, including atmospheric deposition, runoff from land, and industrial discharges [1]. TBT and mercury are among priority hazardous substances identified in the Priority Substances Directive as uPBT (ubiquitous, persistent, bioaccumulative and toxic).

Conclusions

According to the WFD, for those TW systems that did not achieve the good status, it is necessary to develop specific programs of measures to ensure the achievement of good status by the deadline extension to 2027 at the latest. Altough all WBs monitored in our study did not reach the WFD goal, being classified as "not good", it would be important to take into consideration the intrinsic features of each WB when considering these results. Moreover, caution is needed when the environmental quality is assessed by the "one out-all out" principle. One or more BQEs can appear to have a low or a moderate correlation with various stressors, thus leading to a misclassification of the overall status. Finally, a revision of analysis of pressures and a long-term monitoring are required in the management plans aimed at protecting or reclaiming these extremely important environments from both a naturalistic and productive point of view.

Acknowledgments

We would like to thank the Laboratories of Ragusa and Palermo of ARPA Sicily for chemical analyses. A special thanks goes to Dr C. Prinzivalli for useful comments about chemical analyses. We also want to express our gratitude to the German foundation "Stiftung Pro Artenvielfalt" of the Longarini-Cuba wetland-complex for the logistic support during the monitoring activities. This work was supported by ARPA Sicily in the framework of the institutional activities for the implementation of the Italian Legislative Decree (152/06).

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Table 1 – Sicilian TW(s) systems with indications of each Water Body (WB) and its code, identified by the Management Plan of the Hydrographic District of Sicily, typology, geographical references and salinity typology.

TW(s) systems	WB	WB code	Typology	Geographical references (Latitude – Longitude)		WB type* (Salinity)
Oliveri-Tindari	Marinello	IT19TW011313	Coastal ponds	38°08'11"N	15°03'15"E	Euhaline
	Mergolo	IT19TW011315	Coastal ponds	38°08'22"N	15°03'08"E	Polyhaline
	Porto Vecchio	IT19TW011299	Coastal ponds	38°08'30"N	15°03'11"E	Euhaline
	Verde	IT19TW011314	Coastal ponds	38°08'36"N	15°02'53"E	Euhaline
Cape Peloro	Faro	IT19TW001297	Coastal lakes	38°16'06"N	15°38'12"E	Euhaline
	Ganzirri	IT19TW102296	Coastal lakes	38°15'38"N	15°36'59"E	Euhaline
Vendicari	Piccolo	IT19TW085306	Mires	36°48'43"N	15°06'15"E	Hyperhaline
	Grande	IT19TW085305	Mires	36°48'22"N	15°05'54"E	Euhaline
	Roveto	IT19TW085269	Mires	36°47'18"N	15°05'23"E	Mesohaline
Longarini-Cuba	Longarini 1	IT19TW084268	Swamp lake	36°42'33"N	15°00'01"E	Mesohaline
	Longarini 2	IT19TW084267	Swamp lake	36°42'45"N	15°00'30"E	Mesohaline
	Cuba	IT19TW084266	Swamp lake	36°42'24"N	15°01'39"E	Mesohaline
Marsala	Stagnone	IT19TW052302	Coastal lagoon	37°52'22"N	12°27'51"E	Hyperhaline

*Salinity types resulted over the 3-year monitoring period.

Table 2 – Physical-chemical parameters (pH; water temperature, T; salinity, S; dissolved oxygen, DO) expressed as 3-years mean values and range variation (minimum-maximum) in each Water Body (WB); ±s.d. = standard deviation; I.D.L. = Instrument Detection Limit (70 PSU).

WB	Mean pH	Min. pH	Max. pH	Mean T (°C)	Min. T (°C)	Max. T (°C)	Mean S (PSU)	Min. S (PSU)	Max. S (PSU)	Mean DO (%)	Min. DO (%)	Max. DO (%)
Marinello	8.23± 0.05	8.02	8.65	22.6± 0.5	10.3	34.0	31.21± 0.43	15.68	36.85	126.6± 12.3	94.5	184.4
Mergolo	8.04± 0.05	7.82	8.26	21.5± 0.3	9.5	33.4	28.06	22.68	32.52	113.2± 0.4	101.9	125.8
Porto Vecchio	8.11± 0.01	7.86	8.33	22.9± 0.4	10.8	35.4	35.66	32.59	38.78	120.0± 0.7	104.4	142.6
Verde	8.29± 0.08	7.33	8.64	22.1± 0.3	8.8	34.0	33.65	22.73	36.55	128.1± 8.7	97.8	204.2
Faro	8.10± 0.03	7.74	8.53	21.7± 0.2	12.3	30.6	35.85± 0.24	34.29	37.45	117.2± 2.7	91.6	154.9
Ganzirri	8.24± 0.04	7.85	8.96	21.2± 0.2	9.3	31.5	31.98± 0.60	29.35	35.34	117.6± 1.1	38.0	197.3
Piccolo	8.22	7.87	8.62	21.7	12.6	31.3	41.76	18.71	>I.D.L.	109.7	91.6	144.1
Grande	8.39	8.11	8.86	22.2	11.9	33.1	34.66	11.29	64.26	132.9	102.2	203.2
Roveto	8.53	8.22	9.26	21.5	11.4	32.2	18.63	4.18	>I.D.L.	126.3	105.0	171.8
Longarini 1	9.11± 0.23	8.55	10.11	21.4± 0.1	12.8	32.7	10.21± 0.45	3.62	21.25	145.2± 2.7	113.2	188.2
Longarini 2	8.48± 0.27	8.03	8.98	21.1± 0.5	13.1	30.5	20.11± 1.77	7.87	66.84	114.0± 12.9	84.0	144.9
Cuba	8.69± 0.01	8.22	9.33	19.9± 0.4	11.4	28.3	10.34± 0.66	5.09	31.41	114.7± 1.9	100.4	134.2
northern Stagnone	8.32± 0.01	7.92	8.65	21.8± 0.6	10.4	32.1	38.72± 0.65	36.61	44.24	114.3± 10.6	94.0	187.0
central Stagnone	8.37± 0.05	7.99	8.80	21.2± 0.3	10.0	32.1	41.38± 0.30	36.55	48.61	114.3± 1.3	96.7	143.9
southern Stagnone	8.33± 0.06	7.84	8.86	20.8± 0.1	9.9	30.5	40.23± 1.32	35.63	47.85	111.9± 2.8	101.5	126.6

Table 3 – Trophic parameters (DIN, P-PO_4, Chl-*a*) expressed as 3-years mean values and range variation (minimum-maximum) in each Water Body (WB); ±s.d. = standard deviation. *Mean values of two samplings during the year: the swamps were dry in August and in November.

WB	Mean DIN (µM)	Min. DIN (µM)	Max. DIN (µM)	Mean P-PO_4 (µM)	Min. P-PO_4 (µM)	Max. P-PO_4 (µM)	Mean Chl-*a* (µgl^{-1})	Min. Chl-*a* (µgl^{-1})	Max. Chl-*a* (µgl^{-1})
Marinello	32.33± 61.09	3.81	181.54	0.02	0.02	0.02	1.62± 0.99	0.03	3.00
Mergolo	19.45± 15.58	6.95	43.69	0.02	0.02	0.02	1.29± 0.59	0.55	2.08
Porto Vecchio	13.13± 11.97	0.53	36.54	0.03± 0.03	0.02	0.10	0.69± 0.55	0.20	1.44
Verde	13.59± 12.83	1.53	37.16	0.03± 0.03	0.01	0.09	2.83± 2.16	0.52	6.26
Faro	16.47± 13.04	3.44	40.11	0.22± 0.28	0.01	0.88	1.45± 0.99	0.39	3.06
Ganzirri	24.05± 32.39	1.13	93.14	0.09± 0.12	0.02	0.34	55.67± 106.74	1.25	311.87
Piccolo	77.7± 85.20	13.59	202.20	0.11± 0.09	0.02	0.23	7.25± 4.93	0.79	12.39
Grande	106.87± 94.01	7.72	211.90	0.06± 0.06	0.02	0.14	9.23± 12.13	1.70	27.35
Roveto	22.82± 26.29	5.54	61.78	0.06± 0.04	0.02	0.09	24.59± 26.36	0.72	47.87
Longarini 1	113.26± 163.89	0.60	348.38	0.13± 0.16	0.02	0.36	0.84± 1.49*	0.35	1.49
Longarini 2	25.25± 34.67	2.06	88.52	0.28± 0.26	0.02	0.63	8.17± 13.84*	1.72	13.84
Cuba	39.73± 31.05	2.14	76.95	0.06± 0.05	0.02	0.12	2.39± 3.14*	0.60	7.97
northern Stagnone	7.09± 7.24	1.19	22.83	0.03± 0.02	0.02	0.06	0.30± 0.27	0.02	0.84
central Stagnone	12.55± 16.31	1.29	48.57	0.03± 0.02	0.02	0.06	0.28± 0.13	0.09	0.47
southern Stagnone	4.32± 4.32	0.47	11.92	0.04± 0.03	0.02	0.08	0.23± 0.16	0.03	0.49

Table 4 – Concentration values of priority substances that exceeded the maximum allowable concentration (MAC) and the annual average (AA) of the Environmental Quality Standard (EQS) in water and sediment in each Water Body (WB), respectively.

WB	Matrix	Priority substance [conc.]	Value	MAC- EQS	AA- EQS
Mergolo	water	Mercury [µg/l]	0.20	0.07	
Mergolo			0.26		
Porto Vecchio			0.16		
Faro			0.19		
Grande			0.21		
Longarini 1			0.16		
			0.19		
			0.08		
			0.28		
Cuba			0.14		
			0.13		
			0.12		
Stagnone			0.15		
Longarini 1	sediment	Lead [mg/kg]	37		30
Longarini 2		Lead [mg/kg]	137		30
Longarini 2		DDE [2.4+4.4] [µg/kg]	4.6		1.8
Cuba		Lead [mg/kg]	123		30
Cuba		DDE [2.4+4.4] [µg/kg]	3.5		1.8
Stagnone		Tributyltin [µg/kg]	11.5		5.0
			10.8		
			12.6		
			11.4		

Table 5 – Ecological Status (ES), Chemical Status (CS) and Environmental Quality (EQ) of the Sicilian transitional Water Bodies (WBs).

WB	EQB/Index			ES	CS	EQ
	Macroinvertebrates/ (M-AMBI)	**Phytoplankton/ (MPI)**	**Macrophyte/ (MaQI)**			
Marinello	Bad	High	Moderate	Bad	Good	Not Good
Mergolo	Moderate	Good	Poor	Poor	Not Good	Not Good
Porto Vecchio	Bad	High	Good	Bad	Not Good	Not Good
Verde	Poor	Good	Moderate	Poor	Good	Not Good
Faro	Good	Good	Moderate	Moderate	Not Good	Not Good
Ganzirri	Moderate	Moderate	Good	Moderate	Good	Not Good
Piccolo	*[a]	Moderate***	Moderate	Moderate	Good	Not Good
Grande	*[b]	Poor	Moderate	Poor	Not Good	Not Good
Roveto	Bad	Poor	Good	Bad	Good	Not Good
Longarini 1	Poor	Moderate**	High	Poor	Not Good	Not Good
Longarini 2	Bad	Poor**	Moderate	Bad	Not Good	Not Good
Cuba	Bad	Poor**	High	Bad	Not Good	Not Good
Stagnone	Good	High	High	Good	Not Good	Not Good

*Judgment not available: a) the number of species found is not suitable for the application of M-AMBI index, b) absence of evaluable *taxa*.
**Indicative judgment: the MPI index was calculated only three times during the year and not four, the swamps were dried up.
***Indicative judgment: the MPI index was calculated but it is not applicable for the purposes of classification, the mire is hyperhaline.

Table 6 – List of taxa of each Biological Quality Element (macroinvertebrates, phtytoplankton, macrophytes) from the Sicilian transitional Water Bodies.

Taxa	Marinello	Mergolo	Porto Vecchio	Verde	Faro	Ganzirri	Piccolo	Grande	Roveto	Longarini 1	Longarini 2	Cuba	Stagnone
Macroinvertebrates													
Annelida													
Abyssoninoe sp.		+											
Amphitrite cirrata													+
Aphelochaeta marioni													+
Aricidea fragilis mediterranea													+
Aricidea mediterranea													+
Aricidea wassi													+
Capitella capitata					+	+							
Capitella giardi													+
Caulleriella bioculata													+
Ceratonereis costae						+							
Chaetozone gibber													+
Cirratulidae					+								
Cirriformia tentaculata					+	+							
Cirrophorus furcatus													+
Diopatra neapolitana													+
Dorvillea sp.													+
Eunereis longissima					+								+
Euclymene oerstedii					+								+
Glycera alba					+	+							
Glycera sp.						+							
Glyceridae					+								
Hediste diversicolor									+	+	+		
Heteromastus filiformis	+				+	+							
Hydroides elegans					+								
Lanice conchilega						+							+
Leodice antennata					+								
Linopherus canariensis					+								
Lumbrineris coccinea		+			+								+
Lumbrineris latreilli		+	+		+								+
Lumbrineris sp.													+
Lysidice ninetta													+
Maldane glebifex													+
Maldane sarsi													+
Maldanidae													+
Maldanidae indet.													+
Melinna monoceroides													+
Melinna palmata													+
Naineris laevigata	+	+	+	+	+	+							
Naineris sp.	+	+	+	+	+	+							+
Neoamphitrite sp.					+								
Nephtys hombergii													+

Taxa	Marinello	Mergolo	Porto Vecchio	Verde	Faro	Ganzirri	Piccolo	Grande	Roveto	Longarini 1	Longarini 2	Cuba	Stagnone
Nereiphylla rubiginosa		+											
Notomastus latericeus					+								+
Oligochaeta	+			+									
Orbinidae		+	+	+									
Orbinidae indet.	+	+	+		+	+							
Paradoneis lyra		+	+	+	+	+							
Parapionosyllis sp.						+							
Phylo foetida					+	+							+
Phylo ligustica					+	+							
Phylo norvegica						+							+
Phylo sp.													+
Pista cretacea						+							+
Platynereis dumerilii					+	+							+
Polychaeta indet.			+		+	+							
Polycirrus haematoides		+											
Prionospio cirrifera					+	+							
Pseudopolydora antennata					+								
Pseudopotamilla reniformis					+								
Scoloplos armige						+							
Scoloplos sp.													+
Streblosoma sp.					+								
Syllidae													+
Syllis prolifera		+	+	+		+							
Syllis sp.		+		+									+
Arthropoda													
Ammothella longipes													+
Ampelisca sp.													+
Aoridae			+		+	+							+
Apseudopsis latreillii													+
Brachynothus sexdentatus						+							
Caprellidae													+
Chironomidae										+			
Chondrochelia savignyi					+								
Apocorophium acutum					+								+
Monocorophium insidiosum				+		+							
Corophium sp.	+	+		+	+	+							
Cyathura carinata					+								+
Cymodoce truncata					+								+
Elasmopus rapax					+	+							
Elasmopus sp.						+							+
Erichtonius punctatu					+								
Ericthonius sp.		+											+
Gammarella fucicola					+	+							
Gammarus equicauda										+	+		
Gammarus insensibilis						+				+	+	+	
Gilvossius tyrrhenus													+

Taxa	Marinello	Mergolo	Porto Vecchio	Verde	Faro	Ganzirri	Piccolo	Grande	Roveto	Longarini 1	Longarini 2	Cuba	Stagnone
Grandidiriella japonica						+							
Hippomedon massiliensis													+
Idotea balthica						+							
Lysianassina longicornis													+
Microdeutopus gryllotalpa						+							
Microdeutopus sp.						+							
Paguristes eremita													+
Paguristes sp.													+
Paguristes syrtensis													+
Paracerceis sculpta					+								
Perioculodes aequimanus													+
Sphaeroma serratum				+									
Cnidaria													
Actiniaria					+	+							+
Echinodermata													
Amphipholis squamata		+			+	+							+
Asterina gibbosa													+
Mollusca													
Abra segmentum	+	+		+									+
Abra sp.													+
Alvania sp.													+
Cerastoderma glaucum	+		+	+		+						+	
Cerastoderma sp.	+												
Cerithium sp.		+	+		+								+
Cerithium vulgatum			+		+								+
Columbella rustica													+
Conus ventricosus													+
Ecrobia ventrosa				+		+			+	+	+	+	
Euspira intricata													+
Gastrana fragilis			+		+	+							
Gibberula miliaria					+								
Steromphala adansonii					+	+							
Gibbula sp.													+
Glans trapezia			+	+									
Hamionea hydatis						+							
Hexaplex trunculus		+			+	+							+
Loripes orbiculatus		+	+		+	+							+
Mytilaster marioni		+											
Natica stercusmuscarum													+
Odostomia sp.													+
Papillicardium papillosum					+								
Parvicardium exiguum		+	+										+
Pirenella conica							+						
Polititapes aureus			+		+	+							+
Retusa truncatula													+
Rissoa sp.													+

Taxa	Marinello	Mergolo	Porto Vecchio	Verde	Faro	Ganzirri	Piccolo	Grande	Roveto	Longarini 1	Longarini 2	Cuba	Stagnone
Ruditapes decussatus			+	+	+	+							+
Tricolia sp.													+
Tritia coriculum						+							
Tritia cuvierii					+								+
Tritia mutabilis													+
Tritia neritea	+	+		+		+							
Tritia tinei					+	+							
Turbonilla sp.													+
Veneridae				+									
Vexillum sp.													+
Nematoda													
Nematoda	+			+									
Phytoplankton													
Bacillariophyta													
Achnanthes cf. *longipes*	+			+									
Achnanthes longipes									+				+
Achnanthes sp.					+	+							
Amphora sp.p.	+	+	+	+	+	+	+	+					+
Bacillaria paxillifera													+
Undetermined Bacillariales					+	+							+
Undetermined Bacillariophyceae	+	+	+					+	+	+	+		+
Undetermined Bacillariophyta					+	+							+
Bacteriastrum sp.			+										+
Caloneis sp.					+	+							+
Cerataulina pelagica					+	+							+
cf. *Pseudo-nitzschia*		+	+										
Chaetoceros danicus					+								
Chaetoceros decipiens					+								
Chaetoceros simplex					+	+							
Chaetoceros socialis						+							
Chaetoceros sp.p.		+	+	+	+	+	+	+	+			+	+
Chaetoceros tenuissimus					+	+							
Chaetoceros throndsenii						+							
Climacosphenia moniligera	+		+	+	+	+							+
Cocconeis scutellum		+	+	+	+	+	+	+	+			+	+
Cocconeis sp.p.										+	+		+
Coscinodiscus sp.p.		+			+	+							
Cyclotella sp.						+							
Cylindrotheca closterium	+	+	+	+	+	+	+	+	+	+	+	+	+
Cymbella sp.					+								+
Dactyliosolen blavyanus					+								+
Dactyliosolen fragilissimus					+	+							
Diploneis sp.p.	+		+	+	+	+				+	+		+
Ditylum brightwellii					+								
Entomoneis alata													+

Taxa	Marinello	Mergolo	Porto Vecchio	Verde	Faro	Ganzirri	Piccolo	Grande	Roveto	Longarini 1	Longarini 2	Cuba	Stagnone
Entomoneis sp.p.	+	+				+	+	+	+		+	+	+
Fragilaria sp.													+
Grammatophora marina													+
Grammatophora sp.													+
Guinardia flaccida													+
Guinardia striata	+												+
Gyrosigma sp.													+
Haslea sp.		+			+								
Hemidiscus cuneiformis									+			+	
Leptocylindrus danicus					+								+
Leptocylindrus minimus			+										
Leptocylindrus sp.p.		+	+		+								
Licmophora flabellata	+		+										+
Licmophora gracilis													+
Licmophora sp.p.	+		+	+	+	+							+
Navicula sp.p.	+	+	+	+	+	+	+	+	+	+	+	+	+
Undetermined Naviculaceae	+	+				+	+	+		+	+	+	+
Nitzschia longissima					+							+	+
Nitzschia sigma	+	+	+				+	+					+
Nitzschia sp.p.	+	+	+	+	+	+	+	+	+	+	+	+	+
Nitzschiella sp.						+							
Paralia sulcata	+												
Pleurosigma sp.p.	+	+	+	+	+	+	+	+	+	+	+	+	+
Podosira sp.		+			+								
Proboscia alata			+										
Pseudo-nitzschia galaxiae					+								
Pseudo-nitzschia multistriata					+								
Pseudo-nitzschia sp.p.	+	+	+	+	+		+	+	+	+	+	+	+
Pseudo-nitzschia sp.p. of the *Nitzschia delicatissima* complex	+	+	+		+	+							+
Rhizosolenia minima						+							
Skeletonema sp.p.					+								
Striatella unipunctata					+	+							+
Surirella sp.												+	
Synedra sp.p.	+	+	+	+	+	+					+	+	+
Tabellaria fenestrata													+
Tenuicylindrus belgicus					+								
Thalassionema frauenfeldii		+											+
Thalassionema nitzschioides					+	+							
Thalassiophysa hyalina					+	+							+
Thalassiosira sp.p.		+											
Toxarium undulatum	+		+	+									+
Charophyta													
Staurastrum sp.					+								
Chlorophyta													
Cymbomonas sp.					+								

Taxa	Marinello	Mergolo	Porto Vecchio	Verde	Faro	Ganzirri	Piccolo	Grande	Roveto	Longarini 1	Longarini 2	Cuba	Stagnone
Pachysphaera sp.						+							
Undetermined Pyramimonadophyceae	+	+	+	+	+	+		+			+		+
Ciliophora													
Mesodinium rubrum	+		+		+	+							+
Cryptophyta													
Undetermined Cryptophyceae	+	+	+	+	+	+	+	+	+	+	+	+	+
Euglenozoa													
Euglena sp.p.			+	+		+							+
Undetermined Euglenida	+	+	+		+								+
Eutreptia sp.p.		+											+
Eutreptiella sp.p.			+		+	+							+
Katablepharidophyta													
Leucocryptos marina	+	+	+	+	+	+							+
Miozoa													
Akashiwo sanguinea	+	+	+	+	+								+
Alexandrium sp.p.			+	+	+								+
Amphidinium carterae		+											
Amphidinium sp.p.		+			+	+							+
Amphidoma sp.					+								
Cochlodinium sp.p.	+	+	+	+	+								+
Cucumeridinium coeruleum	+				+								
Undetermined Dinophyceae	+	+	+	+	+	+	+	+	+	+	+	+	+
Diplopsalis sp.p.	+	+		+		+							+
Gonyaulax sp.p.		+	+	+	+	+							+
Undetermined Gymnodiniales	+	+	+	+	+	+	+	+	+		+	+	+
Gymnodinium sp.p.	+	+	+	+	+	+	+	+					+
Gyrodinium fusiforme		+	+		+	+							
Gyrodinium sp.p.	+	+	+	+	+	+							+
Heterocapsa sp.p.					+	+							+
Karenia papilionacea					+								
Karlodinium veneficum	+			+									
Kofoidinium velleloides													+
Lebouridinium glaucum	+				+	+							
Oxyrrhis marina						+						+	
Oxytoxum sceptrum													+
Oxytoxum sp.					+								+
Undetermined Peridiniales	+	+	+	+	+	+	+	+	+		+	+	+
Peridinium quadridentatum					+	+							
Phalacroma oxytoxoides					+								
Polykrikos kofoidii						+							
Polykrikos sp.	+		+										+
Pronoctiluca pelagica													+
Prorocentrum cordatum						+							
Prorocentrum gracile	+					+							+
Prorocentrum lima													+

Taxa	Marinello	Mergolo	Porto Vecchio	Verde	Faro	Ganzirri	Piccolo	Grande	Roveto	Longarini 1	Longarini 2	Cuba	Stagnone
Prorocentrum mexicanum					+								
Prorocentrum micans	+	+	+			+							+
Prorocentrum scutellum	+	+	+	+	+	+							+
Prorocentrum sp.p.	+	+	+	+	+	+							+
Prorocentrum triestinum					+	+							+
Protoceratium sp.													+
Protoperidinium cf. *elegans*													+
Protoperidinium divergens	+												
Protoperidinium sp.p.	+	+	+		+	+							+
Protoperidinium tuba					+								
Pyrophacus sp.						+							
Pyrophacus steinii						+							
Scrippsiella acuminata	+	+		+	+	+	+	+					+
Scrippsiella sp.p.													+
Torodinium robustum	+												
Tripos extensus		+											
Ochrophyta													
Dinobryon sp.					+	+							
Undetermined Raphidophyceae	+	+	+	+	+	+	+	+	+	+	+	+	+
Other undetermined phytoplankton	+	+	+	+	+	+	+	+	+	+	+	+	+
Macrophytes													
Chlorophyta													
Aegagropila linnaei													+
Anadyomene stellata													+
Caulerpa cylindracea	+		+										
Caulerpa prolifera													+
Chaetomorpha linum	+	+	+	+	+	+							+
Cladophora albida													+
Cladophora fracta		+											
Cladophora lehmanniana	+												
Cladophora vadorum													+
Cladophora vagabunda	+	+		+		+							
Halimeda tuna													+
Leptosiphonia brodiei													+
Lychaete echinus													+
Ulva laetevirens					+								
Ulva paradoxa	+					+							
Valonia utricularis													+
Ochrophyta													
Cystoseira compressa													+
Cystoseira foeniculacea f. *tenuiramosa*													+
Cystoseira schiffneri													+
Dictyota implexa													+

Taxa	Marinello	Mergolo	Porto Vecchio	Verde	Faro	Ganzirri	Piccolo	Grande	Roveto	Longarini 1	Longarini 2	Cuba	Stagnone
Dictyota mediterranea													+
Gongolaria barbata													+
Hincksia mitchelliae					+								+
Sphacelaria fusca													+
Rhodophyta													
Anotrichium tenue													+
Carradoriella denudata					+								
Ceramium diaphanum													+
Ceramium siliquosum v. *elegans*					+	+							
Chondria capillaris	+												
Chroodactylon ornatum	+												+
Colaconema leptonema													+
Corallina officinalis					+								
Gayliella flaccida	+												
Gelidium crinale					+								
Gymnogongrus griffithsiae					+								
Hydrolithon farinosum													+
Hypnea cornuta					+	+							
Lophosiphonia obscura													+
Palisada patentiramea													+
Peyssonnelia squamaria													+
Polysiphonia breviarticulata	+												+
Polysiphonia scopulorum													+
Rytiphlaea tinctoria													+
Spongites fruticulosus													+
Spyridia filamentosa					+								+
Tracheophyta													
Cymodocea nodosa			+	+	+	+							+
Posidonia oceanica													+
Ruppia maritima	+		+										

CONTROLLING THE EXPANSION OF HALIMEDA INCRASSATA IN THE CABRERA NATURAL PARK USING MARINE ROBOTS AND PHOTO-MOSAICS

Francisco Bonin-Font, Bo Miquel NordFeldt Fiol, Caterina Muntaner Gonzalez, Antoni Martorell Torres

Abstract: Marine invasive macroalgae alter the environment in which they settle, changing food chains, generating structural variations and, sometimes, displacing native species. *Halimeda incrassata* (*H.i.*) is a tropical seaweed that settles mostly on sandy substrates and that has expanded almost sevenfold in the Balearics from 2011 to nowadays. Measuring its coverage is crucial to estimate its expansion rate and plan effective eradication actions. In the last years, the Marine Robotics team of the Systems, Robotics and Vision group (University of the Balearic Islands) has collaborated actively with biologists in the observation of sensible marine habitats using an Autonomous Underwater Vehicle to get data and image processing techniques to infer information of biologic interest. Several marine areas of Cabrera National Park were surveyed by our robot for *H.i.* video recording. Images of videos were used to form photo-mosaics, mark all *H.i.* shoots and calculate automatically its coverage with software. Time, extension and depth of data collection campaigns increase, offering measurements more accurate, and with higher temporal and spatial resolutions than those obtained with traditional techniques based on divers and quadrat frames.

Keywords: *Halimeda incrassata,* Autonomous Underwater Vehicles, Photo-mosaics.

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Francisco Bonin Font, Caterina Muntaner Gonzalez, Bo Miquel NordFeldt Fiol, Antoni Martorell Torres, *Controlling the Expansion of* Halimeda Incrassata *in the Cabrera Natural Park using Marine robots and Photo-mosaics*, pp. 69-79, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.05

Introduction

Marine invasive macroalgae are one of the biggest problems in the Mediterranean because, although their colonization is normally due to human activities, once a species is introduced, it is difficult to eradicate [4]. *Halimeda incrassata* (Bryopsidales, Chlorophyta) (*H. incrassata*) is a tropical alga that settles mostly on sandy substrates colonizing seagrass habitats between 0 and 60 m depth. *Halimeda* species have calcareous (calcium carbonate, aragonite, CaCO3) thallus forming flattened segments. When the alga dies, the chips inside their segments become seafloor or shoreline sediments. The native distribution of this seaweed comprises the Western Atlantic and Indo-Pacific tropical and sub-tropical Oceans. But, in the last two decades Halimeda has expanded to Madeira, Canarias Archipelago, and the Balearic Islands. *H. incrassata* was detected in 2011 in Mallorca, and from then to nowadays it has expanded almost sevenfold in the south-west of the archipelago. Potential harmful impacts of *H. incrassata* on the Balearic ecosystem communities have been already reported [6][12]. However, some authors focus their attention on the positive effects that, until now, *H. incrassata* might be producing when settled, such as, increasing the abundance of fish diversity and the epifaunal assemblages on certain habitats formed on seagrass meadows [13][7]. When dealing with invasive species, controlling their expansion rate is crucial to understand their behavior and to plan effective eradication actions. To control this expansion, coverage turns out to be one of the most important bio-indicators, specially when evaluated along successive seasons. *H. incrassata* coverage has been mostly obtained *in situ* by divers measuring the shoot (i.e. individual plant) density. To this end, cover quadrats (usually 40 x 40 cm or 50 x 50 cm) are set, either along transects or at random sampling locations [7][11]. Then, the number of shoots within them are counted, extrapolating these measurements to greater surfaces.

In general, all diver-based underwater data gathering methods entail similar problems, namely: a) immersions are restricted by the capacity of the scuba air tanks and by the security measures, and limited in depth, time, coverage and extension, b) measurements collected by divers are usually partial, requiring further extrapolations which generate uncertainties [7], c) data geo-referencing becomes really challenging as the depth of missions increases, being inexact or fairly inaccurate; since Global Position Systems (GPSs) work exclusively in air, receivers need to be attached to floating devices and pulled, or, alternatively, GPS reference points need to be created in advance to measure the divers displacement with respect to them [9]. Furthermore, to cover extensive areas many dives of short effective working times have to be performed, increasing human risks and costs. All in all, a good compromise between accuracy and dive effort is required.

Accordingly, innovation in *H. incrassata* studies has to be focused on: a) increasing the spatial and temporal extension of missions, b) enhancing the amount of data collected in each immersion, c) monitoring habitats in deeper areas, d) increasing the accuracy of coverage estimates, and e) georeferencing missions with sufficient precision, in such a way that they can be repeated in successive seasons or times of the year.

Recently, the Marine Robotics team of the Systems, Robotics and Vision (SRV) Group (University of the Balearic Islands - UIB) has collaborated with biologists in the study of sensible marine habitats [2] [8], as one of the strategic lines for research and innovation. Work has been focused on evolving traditional diver-based methods into technology and automated processes, based on marine robotics, software and Artificial Intelligence (AI). Some of these activities included the estimation of *Halimeda* coverage variations at increasing depths, getting images of the sea bottom from an Autonomous Underwater Vehicle (AUV) and building photo-mosaics used to calculate the density of shoots. Advantages of this novel methodology include: a) increasing time, extension and depth of campaigns, b) augmenting the temporal and spatial resolution of data obtained with the AUV with respect to the data obtained with traditional techniques based on divers and cover quadrat frames, and c) increasing the accuracy of the coverage estimations since our method includes all alga shoots in a region with no extrapolations or approximations.

Materials and Methods

The sub-archipelago of Cabrera was one of the prior scenarios for the study of *H. incrassata* expansion in the Balearics [6][7]. Cabrera is a protected National Park located in the south-east of Mallorca and a representative location with a well-defined plan to minimize anthropogenic activities and their impact on the environment. Several marine areas located in Cabrera colonized with *H. incrassata* were surveyed during 2023 and 2024, by an AUV model Sparus II [3], property of the UIB, performing trajectories between 50 m and 70 m long, and between 10 m and 20 m wide. The vehicle moved at constant speeds around 0.18 m/s, altitudes between 1 and 1.5 meters and depths between 13 m and 20 m. Some sample spots of Halimeda located in Cabrera are shown in Figure 1.

Figure 1 – *H. incrassata* pictures courtesy of Fiona Tomás (group Ecology and Marine Resources, Instituto Mediterráneo de Estudios Avanzados, IMEDEA)

Our AUV is torpedo-shaped, submersible up to 200 m, it is 1.6 m long, it has a diameter of 32 cm, and it weighs 60 kg. It is propelled by 2 surge and 1 heave thrusters and it has 8 hours of autonomy. The vehicle incorporates a pressure sensor, a bottom-looking stereo rig, a GPS, a Doppler velocity log (DVL), an inertial measurement unit (IMU), an acoustic modem an eco-sounder pointing down and, finally, two led bulbs (see Figure 2). This robot can be either teleoperated or pre-programmed to perform automatically geo-referenced trajectories of any shape and extension with the unique limits of its own self-power autonomy and its maximum operation depth. Its localization module is formed by a double EKF (Extended Kalman Filter) [15] that integrates all outputs of all the aforementioned instruments. When the vehicle is submersed, it calculates the UTM (Universal Traverse Mercator) geo-location for each point of the trajectory, composing the GPS (latitude and longitude) of a surface reference point with the self-computed vehicle displacement. This capacity of geo-referencing itself enables the vehicle internal system to associate each position to an image. This feature is essential to re-evaluate the evolution of the inspected ecosystems in consecutive months, seasons or years.

Figure 2 – On the left, the AUV schema. On the right, a view of the robot in the sea.

The process per mission can be detailed as follows: a) the AUV records images continuously, at a constant altitude and at a customizable frame rate adequate to guarantee a minimum overlap among successive images or images of adjacent transects, b) in order to reduce the size of the resulting mosaic, original resolution of images is reduced by 4, c) down-sampled images are stitched together accordingly to the AUV self-estimated trajectory, d) zones with image overlapping are homogenized using a Multi-band blending strategy [1], e) all *H. incrassata* shoots are hand-labeled in each image with a graphical image annotation tool [14], f) labeled images are binarized, coloring bounding boxes containing *Halimeda* in black, and the background in white (see Figure 3), g) the same photo-mosaic is built again but with the binarized images, h) margins and zones of the mosaic not included in any of the images are excluded for the coverage because they are neither *Halimeda* nor seabed, i) the coverage is computed as the proportion of black pixels with respect to the total number of pixels (sum of black and white pixels); that is, the proportion of *Halimeda* with respect to the total surface of the surveyed area, excluding margins or zones in between images.

Results

Some illustrative results obtained from three datasets recorded in Cabrera national Park are presented next. Figure 4 shows the trajectory of the vehicle corresponding to the first experiment with 8 transects, all parallel and spaced 1 meter to each other. It is approximately 2 meters wide, 60 meters long, and it was recorded at a constant altitude of 1.5 meters and at a depth of 17 m. The geo-coordinates of the initial point are: (39.1490931024º N, 2.9331163042º E).

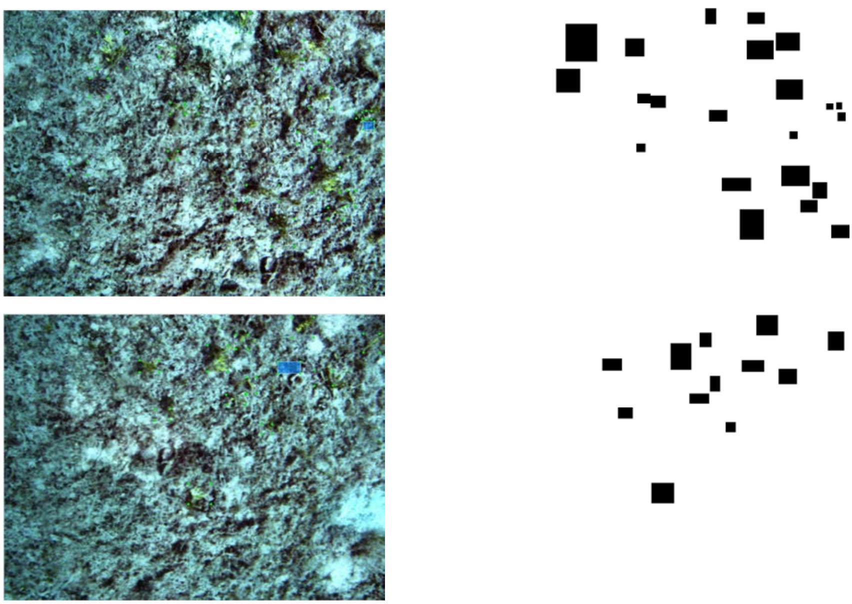

Figure 3 – Left column: two sample images hand-labeled. Right column: their corresponding binarized counterparts, with the *Halimeda* bounding boxes marked in black.

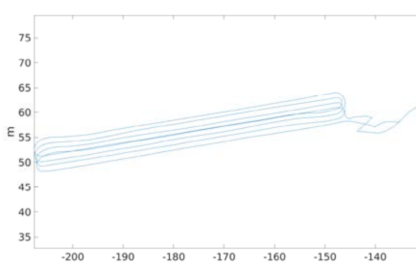

Figure 4 – Trajectory of the vehicle followed in mission 1.

On the top, Figure 5 shows the color photo-mosaic of mission 1, and on the bottom, figure 5 shows its binarized counterpart, where black spots indicate the *Halimeda,* white zones the background*,* and blue zones show the parts of the mosaic that do not correspond to any image. Both mosaics were built with 562 images each one. Let us highlight the correspondence between the trajectory of the vehicle (Figure 4) and the resulting mosaic, as expected. *Halimeda* coverage estimated as explained in the previous section was 0.0033494916 (0.3349 %).

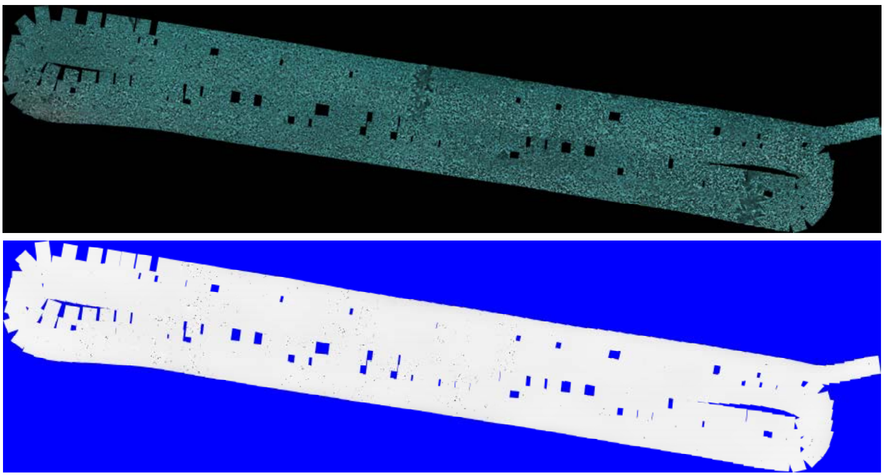

Figure 5 – Mission 1, 16÷17 m depth, recorded from a constant altitude of 1.5 m.

Figure 6 shows, on the left, the trajectory of the vehicle corresponding to mission 2, estimated by the AUV navigation module. This trajectory has a single transect, is 60 meters long, and the AUV tried to navigate at a constant altitude of 1 meter, in an area at a depth of 40 meters. Figure 7 shows, on the top, the color mosaic of this mission 2, with its initial point located around the geo-coordinate (39.1494490903ºN, 2.93431985096ºE). On the bottom, figure 7 shows its corresponding binarized mosaic, where black spots indicate the *Halimeda* and the blue zones indicate the parts of the mosaic excluded from the coverage. Both mosaics were built with 76 images each one. Note how the mosaic presents the same form as the vehicle trajectory. *Halimeda* coverage estimated from this mosaic was 0.0227 (2.27 %).

Figure 6 shows, on the right, the trajectory of the vehicle for mission 3, with 8 parallel transects, each spaced 1 meter apart. The mission was located around the coordinates (39.149410247802734ºN, 2.933732986450195ºE). The trajectory is, approximately, 6 meters wide and 60 meters long, and the AUV navigated at a tentative constant altitude of 1.5 meters, on an area at a depth of 14 m.

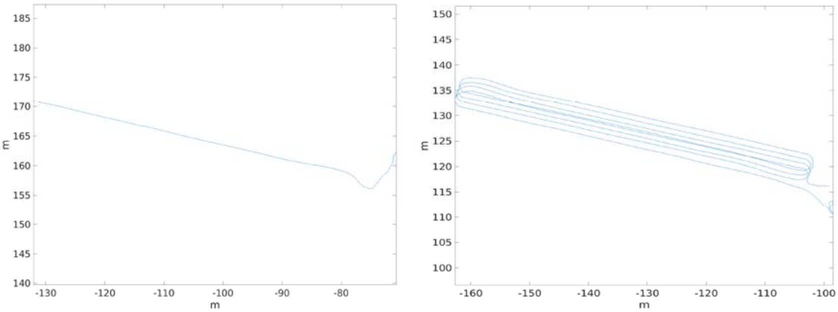

Figure 6 – Trajectories of mission 2 (left) and mission 3 (right).

Figure 8 shows, on the left, the color mosaic of mission 3, and, on the right, its binarized mosaic. Both were built with 333 images each one. *Halimeda* coverage estimated for this dataset turned out to be 0.0253 (2.53 %).

Discussion

According to the obtained results, the method explained in this paper to estimate the density of *Halimeda* in a certain region is suitable if the manual labeling is done by an expert observer, and all spots are market appropriately in all key frames that have to be included in the photo-mosaics. Results show coverages no greater than the 2.5 % in all datasets, which shows a tendency in the whole zone. This process can be run periodically in the same areas and at the same locations, in order to see the progress of coverages in successive seasons.

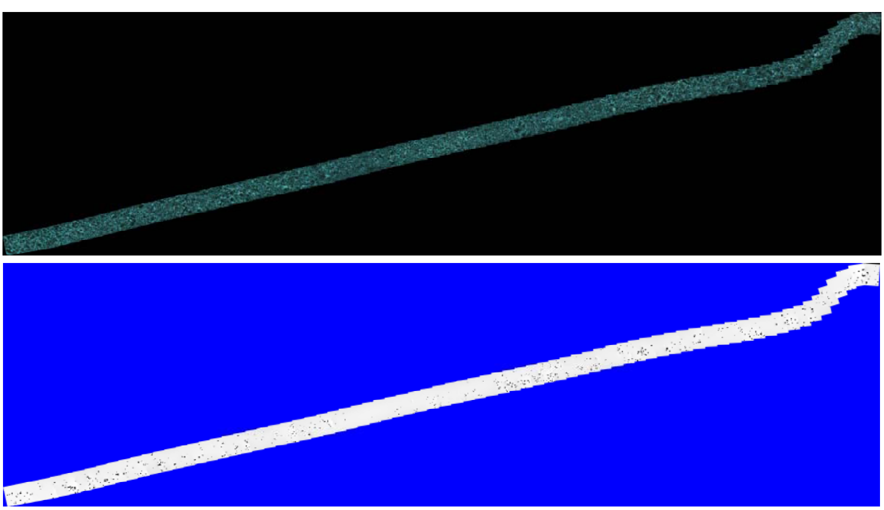
Figure 7 – Mission 2, at 10 m depth, and recorded from an altitude of 1 m.

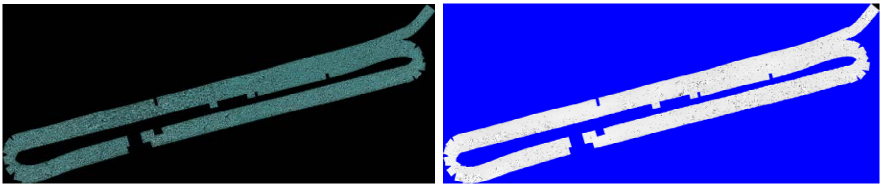

Figure 8 – Cabrera mission 3, 6 meters wide, 60 meters long, recorded at a constant altitude of 1.5 meters and an approximate constant depth of 14 m.

The most challenging aspects of the process can be summarized as: a) images need to be recorded from a mobile platform equipped with a camera that needs to be geo-localized continuously, b) the platform must navigate at an approximately constant altitude, and c) a subsequent process of manual labeling of, in many cases, hundreds of images. Image recording using AUVs solves some of these challenges, since they offer: a) The capacity to program trajectories of any shape that will be executed autonomously at constant altitude or at constant depth, b) The possibility to geo-localize precisely all images recorded during each mission, c) High autonomy to operate during hours in areas as extensive as needed, d) To get depths, in some cases, unreachable by divers without any physical link to any mother-ship or structure. Additionally, all coverages have been estimated without approximations, taking all elements of all images that are identified as *H. incrassata*. This is a clear advance with respect to classical coverage estimations based on divers, manual sampling and data extrapolation. However, this method presents several problems to be taken into consideration before missions are designed: 1- the autonomy of the AUV is limited by the capacity of its battery, 2- a complete disconnection of the AUV from any support vessel or ground station avoids operators to check the evolution of the mission and the state of the vehicle until it emerges, and 3- *Halimeda* spots are quite small, and the vehicle needs to move close to the sea floor (around 1,5 m) for them to appear in the images with sufficient resolution and clarity; the closer the vehicle gets to the sea bottom, the longer needs to be the mission to cover the same area at the same speed, 4- the method, as it is described here, requires the manual labeling of thousands of images making part of the process long and tedious.

Conclusions

Measuring the coverage and expansion rate of invasive marine species, in general, and *H. incrassata* in particular, has become crucial to understand their adaptability to the environment and the affectation to the native habitats. This information is absolutely necessary to plan effective eradication actions or to take advantage of their invasions. Although the benefits of using submarine robots and image processing techniques surpass the problems, the type and the location of the environments or habitats to be evaluated will impose the application of either traditional methods or novel methods like the one described here. This approach, in its current form, enables us to go one step forward in the use of artificial intelligence for submarine habitat assessment. However, our on-going work does even another step ahead, adapting, re-training, validating and testing a specific Convolutional Neural Network (CNN) [10] to be applied in the images recorded by the AUV. The objective is to detect, automatically, all *Halimeda* spots in all key frames used to form the mosaics. This approach replaces the visual identification and manual labeling by a process that can be run in a computer in batch mode, saving a lot of time and human resources, and solving one of the problems mentioned in the *Discussion* section. Although this work in still in progress, it is already giving encouraging results, reducing considerably the human effort necessary to label, frame by frame, the alga. Figure 9 shows 2 images with the *H. incrassata* detected and labeled automatically by one of the first CNN trained models. Finally, let us remark that this method can be applied (and, in fact, it is applied) [5] to study other submarine species. The only difference lies in the target: if it forms larger and more visible or dense structures, such as, for instance, *Posidonia oceanica,* then, its identification on images is easier than *Halimeda* and the AUV can fly at larger altitudes reducing mission times to cover areas with similar extensions.

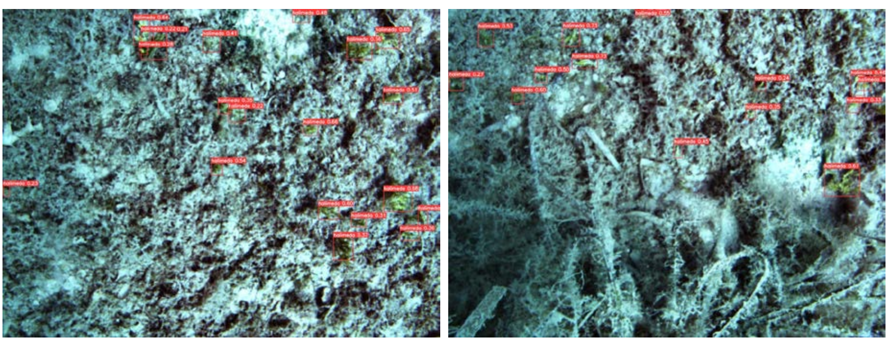

Figure 9 – Two sample images with *Halimeda* inferences output by a CNN trained model.

Acknowledgments

This work has been partially sponsored and promoted by Ministry of Economy and Competitiveness under contracts INVHALI (*Fundación Biodiversidad- Ministerio para la Transformación Ecológica y el Reto Demográfico*), by ERDF A way of making Europe, by Grant PLEC2021-007525/AEI/10.13039/501100011033 funded by the Agencia Estatal de Investigación, under Next Generation EU/PRTR, and by the *Comunitat Autonoma de les Illes Balears* through the *Direcció General de Recerca, Innovació i Transformació Digita*l and the *Conselleria de Economia, Hisenda i Innovació via Plans complementaris del Pla de Recuperació, Transformació i Resiliència* (PRTR-C17-I1) and by the European Union-Next Generation UE (BIO/002A.1

and BIO/022B.1). Nevertheless, the views and opinions expressed are solely those of the author or authors, and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission are to be held responsible.

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MONITORING GELATINOUS ZOOPLANKTON AND ITS DYNAMICS IN THE EASTERN ADRIATIC (2018–2023)

Andrea Budiša, Neven Iveša, Petra Burić, Gioconda Millotti, Moira Buršić, Emina Pustijanac, Ante Žunec, Ines Kovačić, Mauro Štifanić, Nataly Milovan, Paolo Paliaga

Abstract: Gelatinous zooplankton, widespread in pelagic environments, pose a challenge for surveillance due to their delicate, see-through bodies. Their presence often seems irregular, with fluctuating populations occasionally forming dense swarms. These efficient and non-selective feeders compete with fish for resources, and their abundant proliferation can alter the marine food web and result in ecosystem degradation. Hence, monitoring gelatinous zooplankton is crucial. In this study, we document their encounters over six years along the northeastern Adriatic coast, an important spawning area for small pelagic fish now experiencing frequent gelatinous zooplankton blooms. We compare findings from the north to those in the southern Adriatic. Continuous monitoring revealed that the invasive ctenophore *Mnemiopsis leidyi*, predominantly present in the northern basin, significantly altered the taxonomic composition, temporal occurrence, and intensity of gelatinous zooplankton blooms, shifting dominance from native to introduced species.

Keywords: Eastern Adriatic, Gelatinous zooplankton, Istrian coast, Monitoring

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Introduction

Gelatinous zooplankton (GZ) encompasses diverse organisms, including cnidarians, ctenophores, and tunicates [1], which pose a significant challenge for detection and enumeration due to their delicate and transparent bodies. Consequently, direct visual census methods are often employed in their monitoring efforts. GZ plays a crucial role in marine ecosystems, as they are voracious consumers of zooplankton and can have profound impacts on pelagic fish populations [2–4]. Moreover, many GZ species are not commonly preyed upon by other organisms, potentially leading to trophic dead-ends, which may alter the ecosystem's natural structure and energy flows [2].

Enclosed seas, such as the Adriatic Sea and, notably, its northern part (NAd), are particularly susceptible to GZ proliferation, often linked to anthropogenic influences [1, 4]. The NAd, renowned for its biological richness within the Mediterranean [3–5], has witnessed a notable increase in GZ populations attributed to overfishing, climate change, and ballast water discharge [5]. Given the ecological importance of the NAd and vulnerability to such perturbations, understanding the dynamics of GZ populations in this region is imperative. This study seeks to examine the temporal dynamics of GZ populations over a six-year period in the NAd, a region known for its moderate anthropogenic influence and its variable productivity marked by fluctuating freshwater inputs from the west and the presence of highly saline, oligotrophic waters from the south [6,7]. In addition, we contrast these findings to data collected from the southern part of the basin, distinguished by its oligotrophic nature, low primary production [4], and comparingly exposed to less anthropogenic pressure. By examining trends in GZ abundance, taxonomic structure, and distribution, we seek to examine the underlying factors driving their proliferation in this biologically significant area. Ultimately, the presented data should contribute to management strategies to mitigate the negative impacts of GZ proliferation on marine ecosystems and implement sustainable fisheries in the NAd and beyond.

Materials & Methods

Daily monitoring of gelatinous zooplankton (GZ) was conducted from 2018 to 2023 by applying a visual census technique in the coastal waters of the western part of the Istrian peninsula, i.e., 3 km along the coastline of the town Rovinj-Rovigno (~3000 m^2). Specimens larger than 1 cm, discernible to the naked eye, were tallied on-site following the methodology outlined in the literature [3]. Daily observations were conducted from the shoreline, supplemented by snorkeling or scuba diving along transects 1 m wide parallel to the coast, varying according to seasonal conditions and available technical resources. When GZ abundance was high and posed a challenge for enumeration, a cube frame was utilized, as described in the literature [3]. Extreme GZ abundances (>3000 specimens spotted within 2 h), we scanned the rest of the area and gave an estimate of the remaining exact number of GZ. Data collection efforts included ~40 % of reports from local citizens who engage in year-round swimming activities and fishermen trained by the researchers to recognize the species. They volunteered the information and regularly provided photographic documentation of their observations.

The long-term data collection from the NAd was then compared with other studies but also to results gathered during a week-long monitoring cruise aboard a research vessel (Progetto M.A.R.E. 2023) in June 2023 in the archipelago of southern Croatian islands, i.e., the southern Adriatic (SAd), where the same monitoring approach was used to quantify the presence of GZ. Because the taxonomic GZ composition in that area often accounted for great numbers of specimens just over a cm in length, a zooplankton net (WP2) horizontally pulled to filter a known volume of surface water was employed for their exact enumeration.

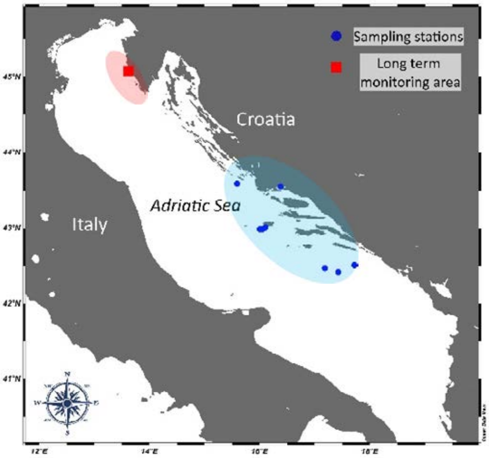

Figure 1 – Study area in the eastern Adriatic: i) long-term monitoring (daily, 2018–2023) along the western coast of the Istrian peninsula in NAd (red), and ii) blue) cruise (June 2023) in the southern part, SAd (blue) - as the data analysed and used for this part of the project have been collected with the contribution of One Ocean Foundation and Centro Velico Caprera within the framework of the M.A.R.E. Marine Adventure for Research and Education project.

In all our monitoring, we observed a particulate GZ on that day, the number of individuals reported, and the abundance. Thus, here we report on the frequency of occurrences of different GZ throughout the year and between years, trends in their numbers, and variability in shares of different taxa in different periods. We expressed the frequency of occurrence as the number (N) of days when GZ was present within a month, regardless of the number of specimens, i.e., GZ days/days in the month.

$$Frequency\ (GZ)[\%] = \left(\frac{N(GZ\ days)}{N(days\ in\ a\ month)}\right) \cdot 100 \qquad \text{(Eq. 1).}$$

Statistical analyses on datasets were performed using R ver. 4.3.1 packages 'stat' and 'FSA' [8, 9]. We expressed the trends as means ± standard deviation (SD) or standard error (SE) or as a confidence interval (CI). In addition, taxonomic diversity indices i.e. Shannon-Wiener (H'), Margalef H, Pielou evenness (J), and dominance index (Y) were calculated applying formulas from the literature [10] while Simpson index of diversity (D) was calculated using the following equation:

$$D = 1 - \left(\frac{\Sigma n(n-1)}{N(N-1)}\right); \quad \text{(Eq. 2).}$$

where n is the number of specimens of one GZ taxa group per m^2 of the studied area, and N is the total number of all GZ per m^2 of the same area.

Results

The taxonomical composition of the reported GZ taxa in the NAd included seven different pelagic cnidarians, one autochthonous and one allochthonous ctenophore, and a pelagic tunicate (Table 1). The overall frequency of GZ occurrences in the NAd remained consistent over the six-year monitoring period, showing no significant differences between years (Kruskal-Wallis test, $H(5) = 5.4$, $p > 0.05$) but varied significantly within a year (by months) (Kruskal-Wallis test, $H(12) = 47.9$, $p < 0.001$) (Fig. 2). The number of GZ reports was the highest in Oct (95 % CI [672, 2219]) and the lowest in Jan (90 % CI [0.5, 2.2]). That dynamic was heavily steered by the oscillations in *M. leidyi* abundance (Fig. 3), on average, over $10.5 \cdot 10^6$ ind. m^{-2} per year and counted for >90 % of all individual GZ reported in NAd. That is 25× higher than the otherwise most abundant *Aurelia* ($4.4 \cdot 10^5 \pm 0.6 \cdot 10^5$ (SD) ind. m^{-2}). Moreover, year-to-year differences are clear when comparing total numbers of ind. revealing the lowest values in 2018 & 2023 ($<5 \cdot 10^5$) and the maximum in 2020 ($>4 \cdot 10^6$), dominated by *M. leidyi* except for 2023 when *Aurelia* spp. took over the first position (Fig. 4). Based on the frequency of encounters over the six years, most GZ were categorized as incidental (Table 1). However, certain cnidarians, such as *Aurelia* spp. and *Cotylorhiza tuberculata*, could be considered as occasional encounters during spring and summer, respectively. The only GZ species with a consistent presence was *M. leidyi* in autumn (Oct–Dec), remaining the sole GZ species present throughout the entire year, while cnidarian *Rhizostoma pulmo* was present for 11 months, albeit being present only ~10 % of the month (Jul, Oct). *Leucothea multicornis*, *Aurelia* spp., and *Chrysaora hysoscella* were present for 9, 8, and 6 months, respectively. Notably, a diverse array of taxa was present throughout most of the year, but only Ctenophora was present in Dec (Table 1). The appearance of *M. leidyi* during the year differed significantly from the other GZ (Dunn test, $p_{adjusted}=0.03$), with noticeably higher abundances recorded (Fig. 5). It was observed that in the first half of the year (January-July), *M. leidyi* was present with a much lower frequency and lower numbers than the other GZ components (Fig. 3&5). For instance, the tunicate (*Salpa* spp.) was most numerous in March ($54 \cdot 10^3$ ind. m^{-2}) while cnidarians reached their maximum in May (*Aurelia* spp. ~$147 \cdot 10^3$ ind. m^{-2}) and June (*C. hysoscella* ~$30 \cdot 10^3$ ind. m^{-2}) but *C. tuberculata* although exhibiting its maximum in August (~$81 \cdot 10^3$ ind.) was consistently outnumbered by *M. leidyi*.

Indeed, from August to December, 95±10 % (SD) of all GZ reported was *M. leidyi* (Fig. 6). This indicates a split in the taxonomic structure of GZ between autochthonous and allochthonous GZ in NAd and highlights a clear periodic dominance of the invasive ctenophore *M. leidyi*.

While non-native taxa largely influenced GZ dynamics in the NAd, in Sad, GZ was predominantly native (Fig. 7) and included the taxa absent in NAd, such as tunicate *Thalia democratica* and ctenophore *Bolinopsis vitrea*. In June 2023, cnidarians were among the most common (>50 %) in both NAd and SAd, similarly frequent as pelagic tunicates in SAd. Higher diversity indices (i.e., D, H', H, J) and dominance index (Y) were found for SAd (0.18, 0.3, 0.96, 0.24, and 0.84) rather than NAd (0.13, 0.3, 0.5, 0.22 and 0.5).

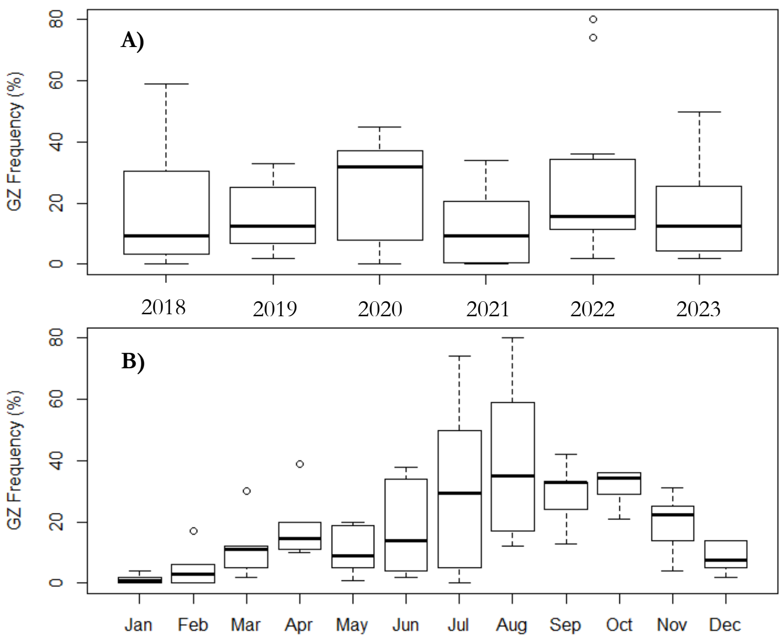

Figure 2 – Frequency of GZ reports in NAd (2018-2023):
A) per year and B) cumulatively within a year, boxes represent 25-75th percentile values, horizontal lines denote medians, whiskers extreme (adjacent) values within 1.5 interquartile range of the 25-75th percentile, and dots values outside the range of adjacent values.

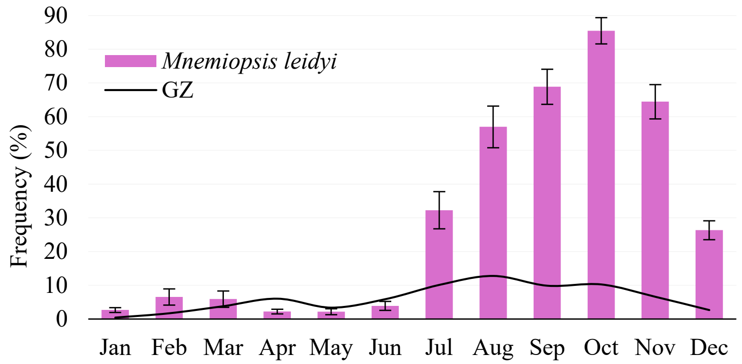

Figure 3 – Fluctuation in monthly frequencies of *M. leidyi* appearances expressed in categories as average ± SE, in contrast to the average monthly frequency of appearance of GZ taxa (N=10) in NAd (2018-2023).

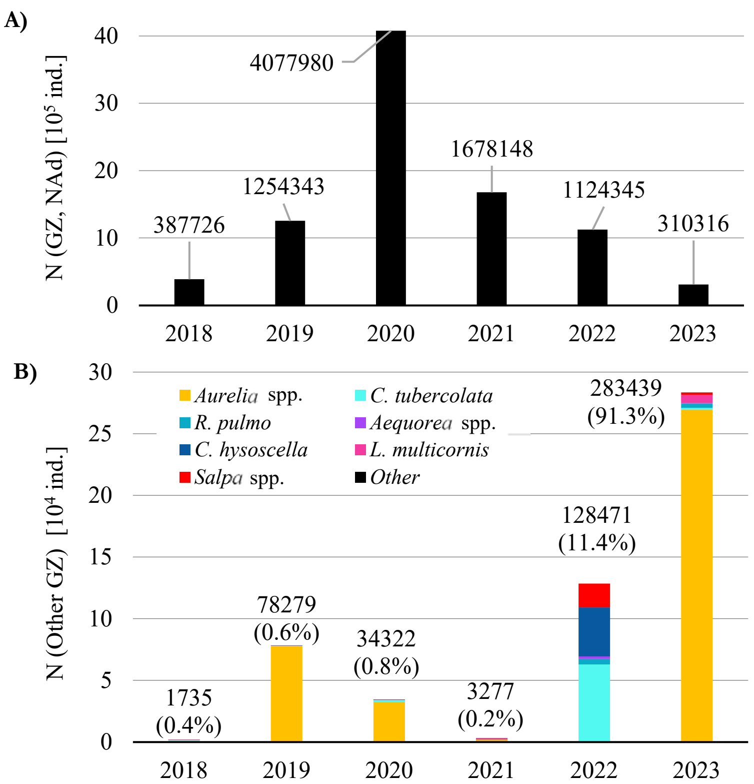

Figure 4 – A) Sum of all GZ ind. in the monitored area in NAd per year, and B) contribution to the total of other GZ aside of *M. leidyi*.

Table 1 – Monthly frequency (%) of encounters (expressed as average ± SE) of various GZ taxa in NAd (2018–2023), i.e. A) cnidarians, and B) ctenophores and tunicates. Encounters with frequencies >50 % are labeled as constant (c) and 25÷50 % as accessory (a), while <25 % are considered incidental.

	Cnidaria						
A)	*Aurelia* spp.	*Cotylorhiza tuberculata*	*Rhizostoma pulmo*	*Aequorea* spp.	*Chrysaora hysoscella*	*Neoturris pileata*	*Pelagia noctiluca*
Jan			0.5±0.2			1.1±0.4	
Feb	4.2±1.2		6.5±1.7				
Mar	13.4±1.9		7±1.4	5.4±0.7			
Apr	38.3±4.7 [a]		2.2±0.5	3.9±0.9	5.6±1.3		
May	16.1±3.6	0.5±0.2	6.5±1.8		4.3±0.8		
Jun	30.6±6.3 [a]	0.6±0.2	4.4±1.1		13.9±3.7		
Jul	10.2±2.7	19.4±5.5	10.2±2.2	2.7±1.1	10.8±3.2		2.2±0.9
Aug	1.1±0.4	44.1±6.6 [a]	5.9±1.4		11.8±3.8		
Sep	1.1±0.5	21.1±2.9	2.2±0.7		0.6±0.2		
Oct	1.6±0.4	2.2±0.7	10.8±1.4		0.5±0.2		1.1±0.4
Nov	1.1±0.5		0.6±0.2				
Dec							

	Ctenophora		**Tunicata**
B)	*Mnemiopsis leidyi*	*Leucothea multicornis*	*Salpa* spp.
Jan	2.7±0.7		
Feb	6.6±2.4		
Mar	5.9±2.4	3.8±1.1	2.7±0.7
Apr	2.2±0.7	6.1±1.2	2.2±0.9
May	2.2±0.9	3.8±0.9	0.5±0.2
Jun	3.9±1.3	5.6±1.1	
Jul	32.3±5.5	9.1±1.5	4.3±1.3
Aug	57±6.2	5.4±1.4	2.7±1.1
Sep	68.9±5.2 [c]	5±1.3	
Oct	85.5±3.9 [c]	1.1±0.4	
Nov	64.4±5.1 [c]		
Dec	26.3±2.8 [a]	0.5±0.2	

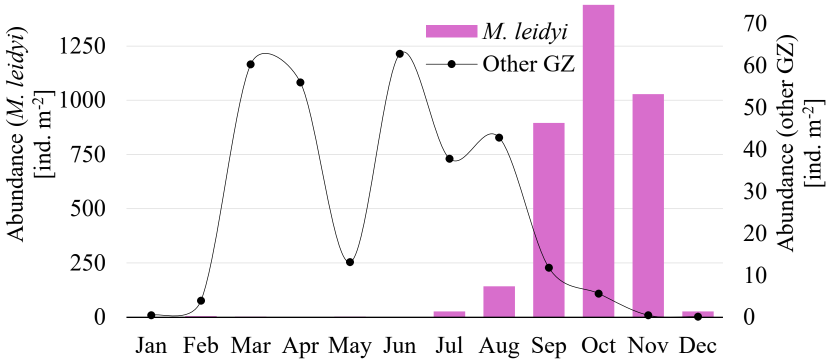

Figure 5 – Average monthly number of *M. leidyi* per m^2 and other GZ taxa through the year (NAd, 2018-2023). The dashed line separates the year to the 1st part when numbers of other GZ are greater from the 2nd part when *M. leidyi* numbers dominate in the GZ community.

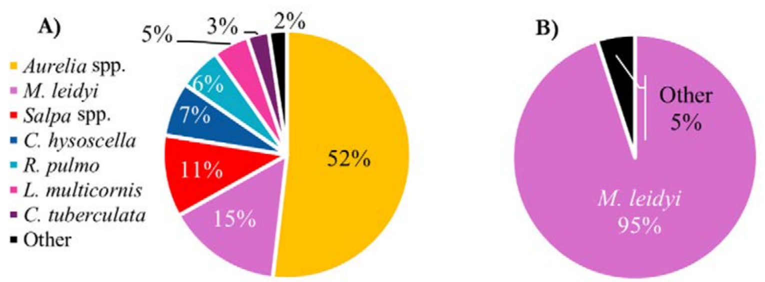

Figure 6 – Different taxa contribution (%) to average monthly GZ abundances (ind. m^{-2}) in NAd, 2018-2023: A) Jan-Jul, and B) Aug-Dec.

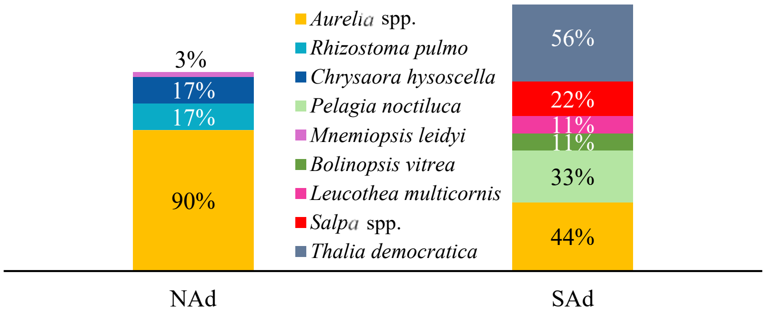

Figure 7 – Frequency of encounters of three GZ groups (Cnidaria – Cn, Ctenophora – Ct, and Tunicata – T) in June 2023 in NAd and SAd.

Discussion

The alien invasive ctenophore *M. leidyi* exerted significant dominance over the GZ community in NAd, both in abundance (>10^6 ind.) and length of its presence – most of the year (Fig. 4–5) and frequency (constant presence Jul–Dec) (Table 1). Many adverse effects of *M. leidyi* in NAd were reported, e.g., damaged fishing equipment [11], reduced zooplankton availability causing anchovy displacement [3], and impacts on nutrients, organic carbon fluxes, and microbial community [12,13]. The biggest proliferation of *M. leidyi* recorded in NAd was reported in 2020 (Fig. 4A), with local maxima of ~450 ind. m^{-2} (e.g., Nov 2020). Conversely, in 2023, *M. leidyi* exhibited its minimum (14× lower than the otherwise lowest in 2018) and has lost its dominant position in the GZ community. We assume that the extreme spring drought in 2023 caused the record reduction of River Po [14] and smaller streams that influenced circulation and nutrient loads in the NAd, affecting primary production and, consequently, higher trophic levels and GZ. Literature mentions incidental *M. leidyi* presence in the Port of Ploče, Sep–Oct [3,4], which raised concern about their spread to nearby pristine areas of Mljet Island (SAd). However, we did not encounter *M. leidyi* in the SAd, in accordance with previous studies [4], and assume morphologically similar *B. vitrea* could have caused confusion as, indeed, we encountered few specimens in the SAd but not in the NAd. However, this is a common spring/autumn species in NAd but rare in the SAd [4]. The presence of autochthonous Ctenophora *L. multicornis* was also incidental with low abundances in NAd, appearing before/together with *M. leidyi* and lasting a few days or weeks. At *M. leidyi* minimum in 2023, *L. multicornis* reached its maximum of 1 ind. per 100 m^2 (~5× higher than the otherwise maximum in 2021), indicating a preferred absence of food competition. In the SAd, *L. multicornis* was the prevalent Ctenophora, albeit in low abundance. These findings align with other reports as it is not a common species and, in Sad, appears in summer–autumn [4].

Among the cnidarians, the incidental *R. pulmo*, accessory *C. tuberculata,* and *Aurelia* spp. encounters were the most common and numerous. *Aurelia* was particularly numerous in 2023 (summer), dominating the GZ community in the NAd, presumably because *M. leidyi* bloom was not particularly extensive. We also encountered *Aurelia* spp. in the SAd, representing the most abundant cnidarian although listed as a rare spring-occurring species in the area (except for the year-round presence of *A. relicta* endemic to Mljet Island [15]). *Aurelia* is a common species in the rest of the basin, particularly abundant in NAd along the Istrian coast and Gulf of Trieste (GoT), where its mass proliferations appear in spring [4]. In 2022, abundance of another cnidarian, *C. tuberculata*, increased 60× with respect to earlier while regularly cooccurring with *M. leidyi* blooms as it was reported most frequently in Aug – when *M. leidyi* becomes constantly present (Table 1). We assume that the different trophic requirements and autotrophic symbiotic zooxanthellae [16] enable it to depend less on food competition with *M. leidyi*. Although listed as a common species in warmer months in the central part of the Adriatic with limited presence in SAd [4], it was not encountered during our cruise. *R. pulmo* was detected in NAd before and during *M. leidy* blooms, increasing substantially in presence in 2022 and 2023, while was not observed in the SAd. Literature reports on its sporadic summer–autumn presence in SAd, with large blooms reported only in the GoT [4]. Moreover, incidentally present hydromedusa *Aequorea* spp. (in NAd), reached its highest abundance in spring 2022 (1 ind. per 2 m^2) but was not recorded in the SAd, which is in accordance with the literature, as its spring blooms in the GoT decrease in abundance southwards [17].

The most frequent stinging jellyfish in the NAd was *C. hysoscella*, which appeared in high numbers only in the summer of 2022, just before massive *M. leidyi* blooms. The species was not found in the SAd, consistently to studies listing it as sporadic, while common (Feb–Sep), albeit seldom in large numbers in the GoT [4]. But decades ago, another stinging Cnidaria – *P. noctiluca,* would periodically dominate harmful GZ in the NAd [18]. Its reappearance happened in 2023, firstly by accessory encounters south (Fig. 7), and progressed northwards to Istria in 2nd half of summer. Indeed, the SAd is known as the area with the most frequent blooms of *P. noctiluca* [4], while its further spread north could have been stopped by the presence of a food competitor – *M. leidyi*, which appeared in that period.

Moreover, pelagic tunicates in the NAd represented only a marginal GZ component, reported as shorth lasting chain-forming *Salpa* spp. encounters (spring 2022 & 2023) along with other typical seasonal GZ. Different feeding patterns, e.g., filtration and diet consisting of protists and phytoplankton [19], rather than zooplankton, probably limited their dependency on competition with other GZ. However, we noticed a higher abundance of pelagic tunicates in SAd compared to the NAd, consistent with other findings mentioning occasional tunicate spring blooms [20]. In addition to sporadic findings, *Salpa* spp. encounters in both areas, in SAd, we witnessed a bloom of *T. democratica*, otherwise absent in the north. The rarest observations in the NAd regarded the newly discovered species: *M. benovici* – not recorded in the SAd, and *N. pileata,* which occasionally appears in the Adriatic and western Mediterranean [21]. Overall, the compared regions were characterized by consistently higher GZ diversity indices in the SAd.

Conclusion

The pelagic coastal waters of western Istria (NAd) are significantly altered by *M. leidyi* which dominated the GZ community 2018–2023, shifting the peak of most GZ occurrences from spring to autumn. Other GZ components (Cnidaria and Tunicata) exhibited accessory/incidental occurrence with an exception in 2023, as a likely consequence of reduced river supplies on the marine food web, resulting in a drastic drop of *M. leidyi* abundance but an increase in native GZ taxa (*Aurelia* spp.). In addition, in the SAd, conditions appear suboptimal for *M. leidyi*, leaving room for more diverse and mainly native GZ taxa dominated by Tunicata and Cnidaria. Moreover, in 2023, *P. noctiluca* reappeared in the NAd, possibly also due to the absence of food competitors such as *M. leidyi*.

Acknowledgment

This research was conducted under the “Marine Adventure for Research and Education” (M.A.R.E.), a project by Fondazione Centro Velico Caprera E.T.S.

with One Ocean Foundation as Scientific Partner. We are grateful for the citizens' contribution, especially to V. Ciceran and R. Marić.

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MONITORING THE MEDITERRANEAN MONK SEAL IN THE CENTRAL MEDITERRANEAN SEA

Luigi Bundone, Aliki Panou, Gema Hernandez-Milian, Giulio Pojana

Abstract: The Mediterranean monk seal *Monachus monachus* was once a common inhabitant of the Mediterranean Sea. Over time, its distribution has experienced a sharp reduction, primarily attributed to various factors stemming from human activities. Known reproductive sub-populations of the species are nowadays concentrated along the coasts of Greece and Turkey. However, occasional but recurrent sightings or movements of individuals are being recorded along most of the coasts in the species´ former distribution range within the Mediterranean Sea. The Marine Strategy Framework Directive require the establishment of monitoring programmes to obtain indicators for the Good Environmental Status of European waters. Here we present the monitoring programmes we carried out on the Endangered Mediterranean monk seal in the central Mediterranean Sea. The output of the work carried out in the central Mediterranean Sea for such a long period of time indicates the relevance of continuous monitoring systems for the monk seal as a top predator in the area. The species may be useful as a key species within the Marine Strategy Framework Directive for Descriptors D1 (Marine Biodiversity), D4 (Food Webs) and D10 (Marine Litter).

Keywords: Marine ecosystems, Biodiversity. Threatened species, Monitoring of coastal ecosystems

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Luigi Bundone, Aliki Panou, Gema Hernandez-Milian, Giulio Pojana, *Monitoring the mediterranean monk seal in the Central Mediterean Sea*, pp. 92-100, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.07

Introduction

The Mediterranean monk seal (*Monachus monachus*, Hermann 1779; hereafter MMS) is the only pinniped species among the marine mammals inhabiting the Mediterranean Basin.

The species was once a common inhabitant of the Mediterranean Sea. However, its distribution and abundance has experienced a sharp reduction over the past millennia, primarily due to various factors stemming from human activities.

With an estimated population of about 400-500 individuals in the Mediterranean Sea, mainly concentrated in its northeastern coasts, namely Greece and Turkey [1], the MMMs is actually an endangered species. Recent studies, however, highlight the MMS´ recovery trend and the possible spread of individuals throughout the Mediterranean Sea [2-4]. It has therefore been very recently categorized as Vulnerable by the IUCN [3].

The Marine Strategy Framework Directive (hereafter MSFD) has been in force since 2008 [5].

Its main objective is to achieve healthy and resilient European marine waters as also their sustainable use using various so-called Descriptors to assess its Good Environmental Status (GES). To accomplish this goal, member states should establish monitoring programmes (MoPs) to gather data on specific criteria and indicators set by the MSFD, covering biological diversity, species populations, habitats, ecosystem functions, as well as human activities and their impacts [6].

Addressing every species in European seas would be unachievable; hence, emphasis has been placed on establishing indicators and criteria focusing on representative ecosystems, species or ecotypes [7]. Furthermore, priority was given to MoPs for endangered species and those relating to Marine Reserves or Marine Protected Areas.

Marine mammals, both cetaceans and pinnipeds, have been used as reference ecotypes within the MSFD in European countries since top predators may act as sentinels of ecosystems or at least provide a reference for understanding impacts on the environments [e.g. 8, 9].

The NGO "Archipelagos - environment and development" has been monitoring the MMS for over 35 years within the central Ionian Sea, Greece. Additionally, and in parallel with its Italian branch, "Archipelagos - ambiente e sviluppo, Italia" it has conducted studies on the species' distribution and ecology in the Adriatic Sea in collaboration with national institutions and NGOs based in this region.

Here we list the MMS monitoring programmes carried out by the two "Archipelagos" sister organizations in the Adriatic-Ionian Region over the last 35 years. As the species is a top predator, such data may be useful for three Descriptors of the MSFD.

Materials and Methods

We examined in detail the monitoring programmes on the MMS we carried out in the Ionian-Adriatic region, namely Greece, Italy, Albania, Montenegro and Croatia, with various levels of effort through time.

Our monitoring programmes embrace: (A) recording and evaluation of seal sightings, (B) Monitoring habitat availability and the use of terrestrial habitats by the species, (C) Individual identification carried out through systematic photo-identification programmes and opportunistic collection of photographic material. Cases of strandings and by-caught individuals were also recorded over long periods of time.

Finally, the collection and analysis of MMS faeces allowed to carry out trophic and contaminant studies.

Results

Biogeographical reviews of available data on the presence of the MMS were preliminarily carried out, with the exception of Croatia, for the countries surveyed [10-15].

Our monitoring programmes can be structure in three main key points:

A Seal sightings

Seal sightings were recorded in the entire Ionian Sea in Greece (1985-2023) [15-18], in Southern Apulia in Italy (2011-2023) [2, 12], in Albania (2018-2022) [10, 11], in Montenegro (2013-2017) [14, 15, 19] and in Croatia (2011-2013) [2, 20].

Seal sightings were recorded using the interview protocols of the two NGOs, in order to evaluate the reliability of the data. Whenever available, photos and videos documenting these encounters were also collected from all countries.

In June 2017, the very first video documentation of an MMS encounter in Southern Apulia was recorded [21].

MMS sightings in Montenegro continued to be recorded from our local collaborator. In August 2023, the very first video documentation of an MMS encounter in the country was recorded (Dušan Varda, *pers. comm.*).

B Terrestrial habitat

The terrestrial habitat (marine caves with beach/es inside) was monitored along numerous coastlines to establish habitat availability and abundance in each region (Fig.1). The marine caves suitable for the MMS where then regularly surveyed to verify their effective use by the seals through visits either for detecting seal tracks or presence or through camera traps for obtaining pictures of seals.

<u>Greece</u>

- Central Ionian Sea: years 1985-2002, 2018 - present [13, 16, 18, 22].
- Zakynthos, southern Ionian Sea: years 1989-1992, 1997-1999 [23-25].
- NW Corfu: years 2021 - present [26]. The use of one cave was confirmed.

<u>Italy</u>, Southern Apulia: years 2011-2015 [12, 27]. No cave use was confirmed.

<u>Albania</u>: Karaburun-Sazan: year 2019 [10, 11].

In August 2019, it was recorded the very first documented use of cave in the country by the recovering of a monk seal scat. Cave use was confirmed afterward by infrared cameras installed in caves (2020-2021) [11].

<u>Montenegro</u>, entire coastline: years 2013-2015 [28]. No cave use was confirmed.

<u>Croatia</u>: Istria/NW Croatia: years 2011-2013 [20].

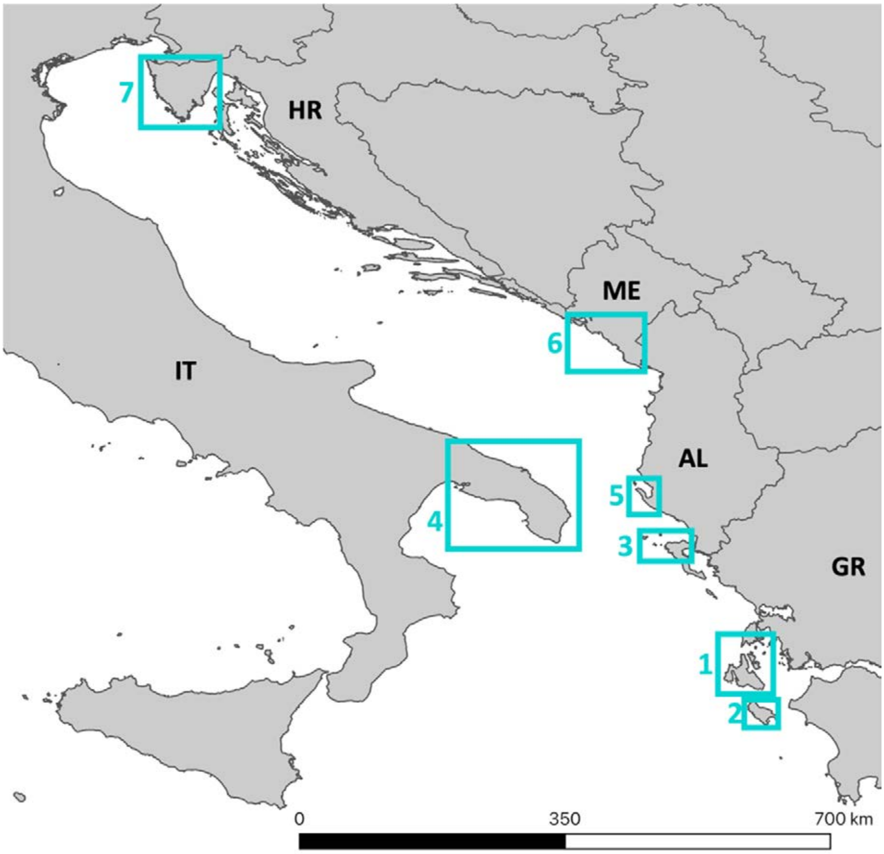

Figure 1 – Research areas: Greece, central Ionian Sea (1), Zakynthos (2) and Northern Corfu (3); Italy, Southern Apulia (4); Albania, Karaburun-Sazan (5); Montenegro (6); Croatia, Istria (7).

C Photo-identification

Systematic photo-identification was carried out using camera traps in Greece (2018 - present) and in Albania (2019). Additional data was collected through opportunistic surveys (own data and citizen science). In the central Ionian Sea, Greece (2018-2023), 25 sub-adult and adult animals (Fig. 2) were identified and the use of one cave in NW Corfu by 2 seals was documented.

In Albania (2022), two individuals were documented [11].

In Croatia, Istria, own data collected through opportunistic surveys and data obtained though citizen science, allowed the identification of an adult female frequenting mainly the northern coast of the country [20].

Additionally, bycatch of MMSs in coastal fishing gear has been monitored within the framework of several early projects in the eastern Ionian Sea [13, 29, 30].

Figure 2 – Adult male captured by infrared cameras and subsequently identified in the central Ionian, Greece.

More recent monitoring work includes the analysis of the MMS´ diet from faeces collected in marine caves (Fig.3) in the countries mentioned above (1998 – present), except for Montenegro [11, 31].

Finally, an innovative study on microplastics (Fig.3) and their additives in monk seal faeces from Zakynthos Island, eastern Ionian Sea, has been carried out [32].

Figure 2 – Monk seal faeces (left), diet remains (center) and a fiber (right) found in faeces.

Discussion

The overall output of the above monitoring programmes indicates the relevance of continuous monitoring systems for the MMS as a top predator and is described in detail in the relevant bibliography. But the species might also become a useful key species within the MSFD for three Descriptors: D1, D4 and D10, as several on-going MMS monitoring programmes of various NGOs will obviously be continued, and new programmes may be launched. Here, price vs. value of the various MSFD MoPs should also be considered, of course and existing monitoring programmes may be useful at the same time for the overall evaluation of the GES in each Member State.

Furthermore, data obtained through the NGOs´ monitoring programmes might also be valuable for the use of innovative modelling tools within the implementation of the MSFD as described in Lynam et al. 2016 [33].

The studies focusing on the MMS' biogeography, sightings, terrestrial habitat availability and use, photo-identification, by-catch and strandings provide insights into potential indicators of the species' abundance and distribution (Biological Descriptor -D1).

The trophic ecology of the various species in the marine ecosystem is addressed by the Food Web Descriptor (D4), using stomach content analysis. Incorporating information about top predators into this Descriptor presents challenges due to the difficulty of obtaining samples from carcasses. However, the use of seal faeces can serve as a valuable alternative tool for acquiring pertinent information for this Descriptor [e.g. 9]. Concerning the MMS, such samples can easily be collected in caves during the monitoring activities, either within dedicated programmes for assessing the use of caves by the MMS or during occasional monitoring of caves.

Marine litter impacts are considered in the Descriptor (D10). Again here, during MMS monitoring programmes, samples can be collected to analyse the incidence of microplastics, and even macroplastics, in faeces of the MMS as a marine top predator (Criterion 3, amount of litter and micro-litter ingested by marine animals). Here, the recommendations of Gago et al. (2016) [34] should be taken into consideration as well.

The difficulties in obtaining information on this species stem from two factors: (1) challenges in studying it due to their distribution, abundance, habitat use and ecology in general, and (2) the lack or limitation of financial resources for many NGOs already conducting these studies, and despite their significant expertise and specialization.

Collaborative efforts with national institutions (e.g. ministries, research institutions, universities, etc.) and the provision of funding resources might be the most effective strategy for meeting the requirements outlined by the EU within the MSFD, particularly regarding assessments of top predators such as the MMS.

Acknowledgments

We would like to thank the many dozens of volunteers who helped all these years in our monitoring programmes.

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ECOLOGICAL ZONATION AND ABIOTIC VARIABILITY IN AN ENCLOSED NATURE PARK: THE CASE OF THE SALINI SALTWORKS IN MALTA

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Abstract: The Salini saltern complex (SSC), was a natural wetland that now functions as a nature park. The SSC is oriented along a NE to SW axis measuring 740 m by 140 m, with a surface area of 90000 m^2. It comprises two reservoirs at the seaward extremity (each 12000 m^2 in area) and 33 smaller pans in the inland portion, with surface areas ranging from 900 m^2 to 2000 m^2. This study addressed a knowledge gap by recording abiotic and ecological conditions across the SSC and relating them to the external marine conditions. The salina was visited monthly between 25 July 2022 and 5 July 2023. During each visit, the temperature, pH, electrical conductivity, nitrate and phosphate concentration of water were measured in the open sea, in the two reservoirs, and in 15 pans. The diversity of macroalgae, spermatophytes, and non-planktonic fauna was evaluated through direct observation, collection of specimens and photographic monitoring. Water quality changed in spatial and temporal dimensions within the SSC. The principal trend was a sharp gradient of abiotic conditions along the primary axis of the SSC from the seaward side to the landward side, suggesting changes in the characteristics of water during its movement from the open sea into the reservoirs and the pans. The species richness increased from the open sea to the reservoirs and decreased to much lower levels in the pans. The elevated species richness in the reservoirs is attributable to the higher stability relative to the sea and pans.

Keywords: salinas, Malta, electrical conductivity, species richness

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Martina Busuttil, Robin Caruana Montaldo, Lena Ehmcke, Elise Bartl, Francesco Giacalone, Alessandro Giuffrida, Sarina Hilke, Giulia Lembo, Andrea Li Vorsi, Shona Murphy, Elia Ponte, Natalia Szklarczyk, Katya Debono, Belinda Gambin, Sandro Lanfranco, *Ecological zonation and abiotic variability in an enclosed nature park: the case of the salini saltworks in Malta*, pp. 101-111,
DOI: 10.36253/979-12-215-0556-6.08

Introduction

The climatic and oceanographic conditions in the central Mediterranean, characterised by long, dry summers and mild, wet winters on microtidal shores, are ideal for the natural evaporation processes required for salt production. Over centuries, these conditions have been exploited for economic purposes through the construction of 'salinas', coastal complexes focused on the production, harvesting, and storage of sea salt. Although the practice continues to the present-day, modern salinas not only serve economic purposes but also have significant ecological roles [1, 2], with many transformed into nature reserves, providing critical habitats for various species. These habitats, characterised by high salinity and fluctuating water levels, support uncommon communities adapted to these conditions. The relatively undisturbed nature of most salinas, due to their remote locations and regulated human intervention, has allowed these ecosystems to persist over time [3].

The Salini Saltern Complex, henceforth referred to as the 'SSC', is the largest saltworks facility in Malta, and forms part of the Salini Nature Reserve, a managed protected area. The SSC measures approximately 740 m by 140 m, with a surface area of 90000 m^2 and is oriented along a NE to SW axis. It comprises two large reservoirs at the seaward extremity (each 12000 m^2 in area) and 33 smaller enclosures ('pans') in the inland portion, with surface areas ranging from 900 m^2 to 2000 m^2 (Figure 1). The top of the walls of the pans are approximately one metre above mean sea level, although the height difference between the top of the walls and actual sea level changes depending on microtidal variations and marine surges. The SSC receives water from the sea through the two large reservoirs at the seaward end and a series of channels convey the water to the 33 inner pans. The SSC also receives episodic freshwater input from rainfall and surface runoff.

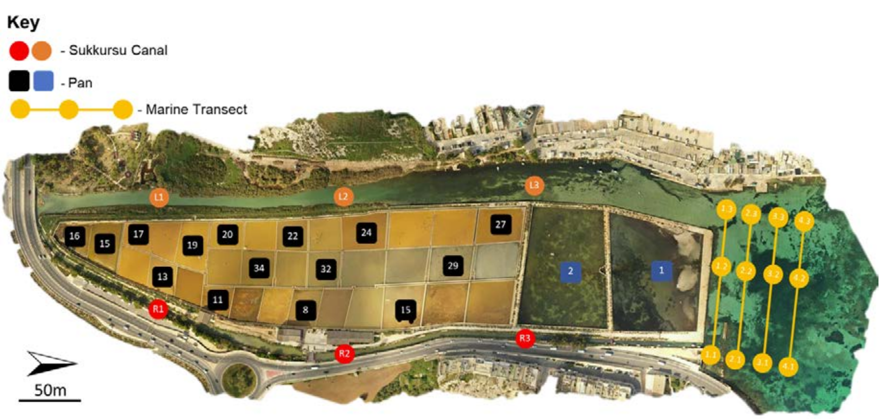

Figure 1 – General view of the SSC and the adjacent marine environment. The arrow at lower left indicates North. The numbered saltpans are the ones that were sampled during this study. Pans 1 and 2 are the large 'reservoirs'. The 'Sukkursu' canal is a seawater channel that encircles the SSC and opens to the sea at both ends.

General Aim

Although the SSC has been the subject of recent studies [4, 5, 6], these have either focused on a specific taxon, usually avifauna, or have assessed the nature reserve in isolation with little regard for its external context. There is little consistent information regarding the variation of physico-chemical conditions in the SSC and their possible linkages with the marine environment, from which almost all their water derives. This study therefore aimed to address this knowledge gap by recording trends in abiotic and ecological conditions across the primary axis of the SSC over a period of one year and relating them to the external marine conditions.

Materials and Methods

The broad aims of the study were achieved by measuring 'water quality', defined as the temperature, pH, electrical conductivity, nitrate concentration, and phosphate concentration of water and the overall 'biological characteristics', described by 'plankton', macroalgae, spermatophytes, and macrofauna in representative parts of the SSC and its environs over the period of study. Subsequent analysis of these data elucidated any relationships between abiotic gradients and biotic characteristics.

Data were collected from several sample sites within the SSC and its immediate environs (Figure 1) as follows:

(1) The open sea outside the salterns. This was sampled along three virtual transects, with six sample points on each transect, giving a total of eighteen sample points.

(2) The two large reservoirs at the seaward part of the SSC, each of which represented one sample point.

(3) The 'inner pans': a sample of 15 from the 33 smaller saltpans were selected for study. The 15 pans were selected systematically, ensuring a spread of sample sites from the seaward part to the landward part. The individual pans were numbered sequentially for ease of identification.

Collection of data

The SSC was visited at approximately monthly intervals for one calendar year, between 25 July 2022 and 5 July 2023. Visits were generally carried out during the late morning and early afternoon, to maximise comparability of measurements recorded during different sessions. During each visit, the water parameters of interest were measured in all sample points (18 in the open sea, the two large reservoirs, and 15 smaller pans). The diversity of plankton, macroalgae, spermatophytes, and non-planktonic fauna (excluding interstitial fauna) was evaluated through the methods described later in this section

Water quality

Electrical conductivity (EC), pH, water temperature, nitrate concentration, and phosphate concentration were measured monthly at each sample point during every field visit using Hanna Instruments HI98194 and HI9829-13042 multiparameter meters that were calibrated before use. In each case five replicate readings were taken and averaged. In parallel with this, pH and water temperature were also measured at 90-minute intervals throughout the duration of the study, in the two large reservoirs using two HOBO Onset MX2501 data loggers. These were initially installed on July 25, 2022, and remained submerged in the water until April 3, 2023. The loggers were only taken out of the water briefly during the monthly visits to download the data and reinitialise them.

Measurement of nitrate and phosphate concentration was carried out in the laboratory after each field visit. Water samples were collected from each sample point, transported to the laboratory in a refrigerated container, and subsequently stored at a temperature of -20C until analysis. Nitrates were measured using a Hanna Instruments HI96786C Nitrate ISM spectrophotometer. Phosphates were measured using a Hanna Instruments HI83399 for 'ultra-low range' phosphates, and a Hanna Instruments HI97713 for 'low range' phosphates in cases where the phosphate reading exceeded the range of the HI83399 device. Device protocol was followed for all nitrate and phosphate measurements.

Plankton

'Plankton', here defined as microscopic organisms passively transported by water currents, were considered as a single functional group to give an indication of the comparative productivity across sample sites. A volume of 0.5 L of water from the surface layer (0-50cm depth) was collected from each sample point during every visit and refrigerated at 4C. These were subsequently transported to the laboratory and analysed as soon as possible. Initial microscopic surveys were carried out on unmodified samples whilst enumeration of plankton was carried out following fixation with Lugol's Iodine. To ensure an even distribution of any plankton present, the water samples were gently shaken prior to microscopic examination. Plankton densities were determined through direct enumeration of plankton cells or aggregates in water. Subsequently, one drop from each sample was taken, transferred into a glass cavity slide, and examined using a Bresser ADL 601 microscope, equipped with a Nikon D5300 Digital Camera. Five micrographs were captured at a magnification of x100. This process was repeated ten times for every sample. All micrographs were subsequently processed using ImageJ 1.53c [7] to facilitate supervised counting of plankton. Planktonic microorganisms were identified to the lowest taxonomic level possible considering the instrumentation available.

Macroscopic fauna

Macroscopic fauna in the two large reservoirs were monitored through analysis of video recordings. Two GoPro Hero 10 cameras were installed in these sample sites and were programmed to record video continuously for approximately 45 minutes during each visit.

Data from the marine sample points was collected by conducting underwater visual surveys (UVSs). These surveys involved establishing a transect measuring 150 m in length and 2 m in width. To ascertain this distance accurately, the cycle kicks during the 150 m swim were tallied. The combination of cycle kick counts, navigation proficiency, and the utilisation of GPS data confirmed both the length and direction of the transect [8]. Data acquisition employed a non-invasive approach through the utilisation of video capture using a GoPro Hero 10 camera to mitigate potential biases and induced behaviours during the research [9, 10, 11]. Video footage of the transect was systematically recorded at regular intervals to provide a comprehensive record of species presence and abundance that was subsequently subjected to detailed analysis [9]. Transect surveys were rigorously conducted in accordance with a standardised fish visual census protocol [12]. Adherence to this protocol necessitated maintaining a consistent swimming speed of approximately ten metres per minute for each 50 metre transect, resulting in an average survey duration of around five minutes. While executing the survey, a two-metre distance on either side of the transect midline was diligently observed while swimming at the water's surface. Ensuring a minimum spatial separation of 20 metres between consecutive transects was imperative. Upon the completion of each transect, reviewing the virtual transect allowed for the analysis of photographic data portraying the habitat landscape and any observed instances of fish sightings. To address the challenge of counting fish within large groups, the frame-by-frame mode, in conjunction with the geometric measurements tool, was employed. This approach facilitated precise and systematic fish counting to differentiate individual fish within shoals. The combined use of ethograms, species-specific coding, and geometric measurements offered a comprehensive method for accurate and detailed counting of fauna.

Spermatophytes and macroalgae

Spermatophytes and macroscopic algae were systematically sampled through direct observation by traversing the sample sites in a grid pattern. Each specimen encountered was collected, stored in a refrigerated plastic container, and transported to the laboratory for analysis. Each specimen collected was initially examined using an AmScope stereo microscope at magnifications up to x45. Where necessary, specimens were further examined using a Bresser ADL 601 microscope at a magnification of x100. Specimens were identified to the lowest possible taxonomic level using various guides [13, 14].

Management and analysis of data

All data collected was coded in ‘tidy’ format [15] and analysed using R [16] through the RStudio interface [17].

Results

Water quality: spatial variation

The physico-chemical characteristics of the water in the marine samples and in the samples taken from the SSC are summarised in Table 1 and in Figures 2 to 4.

Table 1 – Water quality parameters in the sea and in the SSC (large reservoirs and small pans considered together). The pH value marked with an asterisk may represent instrumental error. Mean values are accompanied by the standard deviation.

Parameter	**Range (Marine)**	**Mean (Marine)**	**Range (SSC)**	**Mean (SSC)**
EC (µS/cm)	4320 ÷ 59740	52351 ± 9320	1425 ÷ 200000	109389 ± 40423
pH	6.28 ÷ 8.44	7.90 ± 0.37	6.30 ÷ 14.00*	9.03 ± 1.89
Nitrate (mg/L)	0.10 ÷ 68.10	7.96 ± 11.33	0.4 ÷ 99.3	11.20 ± 16.84
Phosphate (mg/L)	4.00 ÷ 2500.00	121.60 ± 259.28	1.0 ÷ 2500.0	122.02 ± 339.55

The results indicated that the principal trend in water quality was a gradient of electrical conductivity (EC), pH, and nitrate concentration along the primary axis of the SSC from the seaward side to the landward side, suggesting clear changes in the characteristics of water during its movement from the open sea into the reservoirs and the pans. The spatial trend was statistically significant for EC and pH and marginally non-significant for nitrate concentration (Table 2). Variations in the phosphate content of the water showed no discernible spatial pattern between the open sea and SSC (Figure 2).

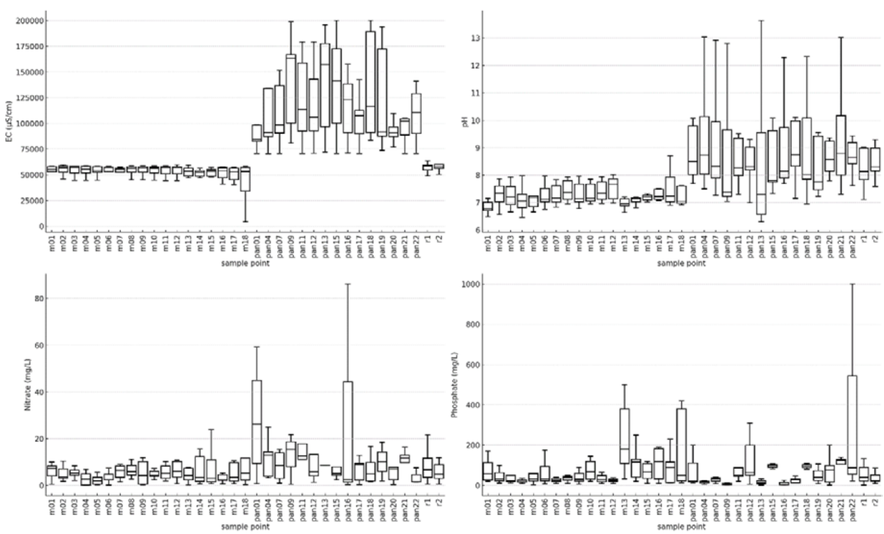

Figure 2 – Variation of four physico-chemical parameters (EC, pH, nitrate, phosphate) in the marine sample points (m01 to m18), the large reservoirs (r1 and r2) and the inner saltpans (pan01 to pan15).

Table 2 – Comparison of the median value of four physico-chemical parameters in the marine sample points and the SSC. The p-value represents the probability of a statistically significant difference between the marine samples and those taken from the SSC.

Parameter	Median (Marine)	Median (SSC)	t	p
EC (µS/cm)	55550	96700	-25.33	< 0.0001
pH	7.16	8.34	-14.9	< 0.0001
Nitrate (mg/L)	3.8	7.6	-1.80	0.075
Phosphate (mg/L)	38.0	37.5	0.43	0.670

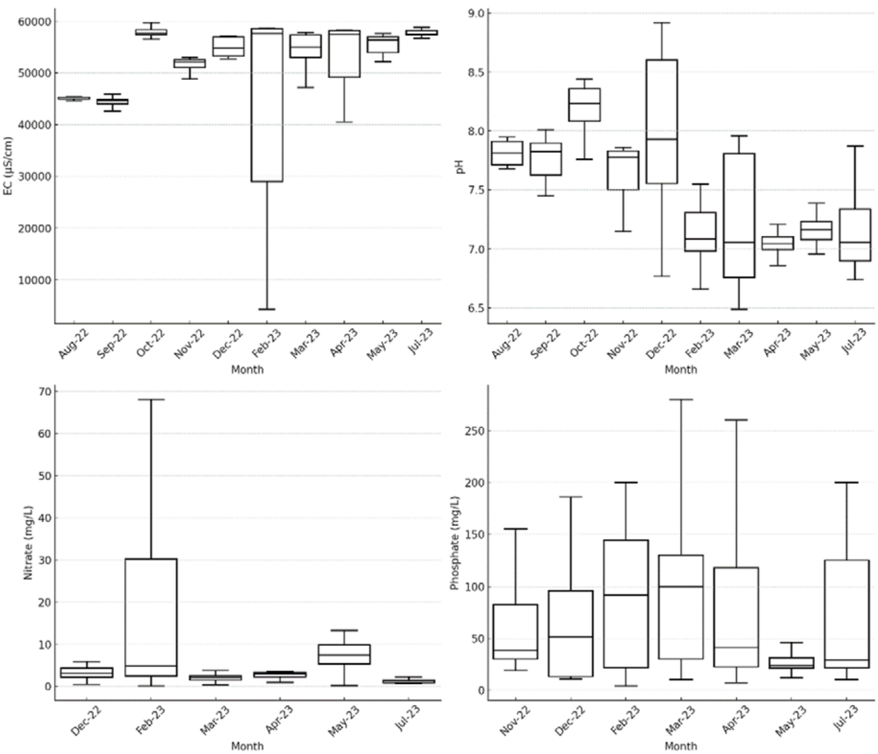

Figure 3 – Variation of four physico-chemical parameters (EC, pH, nitrate, phosphate) across all sample points in different months for the marine samples.

Water quality: temporal variation

Temporal variations in pH on daily and seasonal scales were unremarkable and reflected predictable patterns driven by photosynthetic activity, whilst EC, nitrate, and phosphate concentrations showed no discernible trend over one calendar year (Figure 2). Conditions in the innermost saltpans, those furthest from the sea, were extreme during the dry season with supersaturated hypersaline water, underwater precipitation of evaporites, and water temperatures sometimes exceeding 50 °C. It should be remarked that some very high pH values (approximately pH 14) recorded from the inner saltpans were initially assumed to be the results of instrumental error. These measurements were however repeated with separate instruments, giving very similar results.

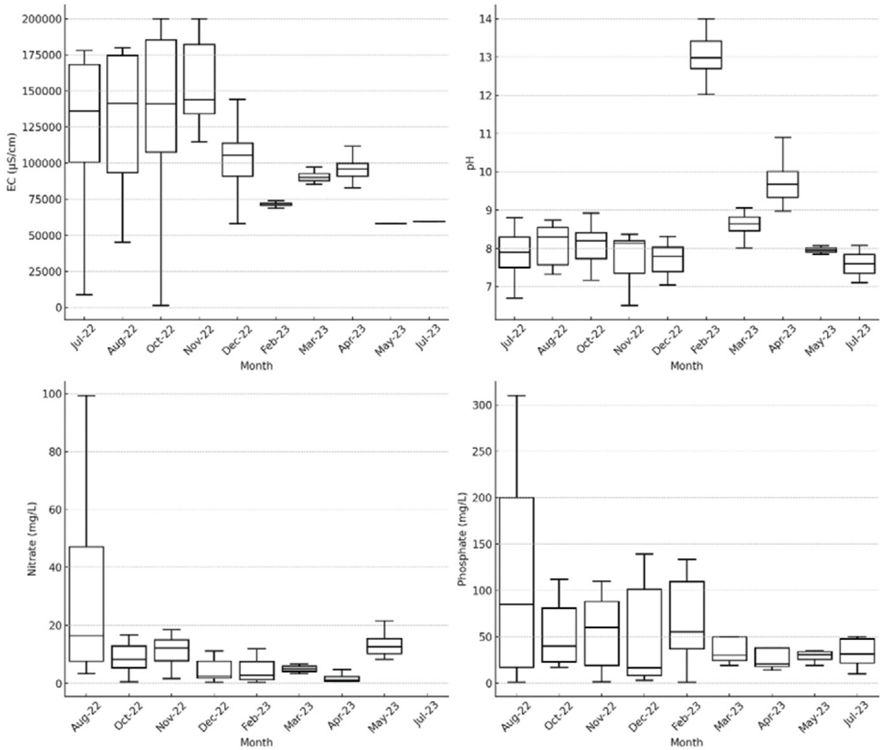

Figure 4 – Variation of four physico-chemical parameters (EC, pH, nitrate, phosphate) across all sample points in different months for the saltpan samples.

Biota

The results of the 'biodiversity' surveys are here summarised qualitatively. This assessment highlighted a clear decrease in species richness from the large reservoirs to the inner saltpans. The reservoirs, characterised by more stable conditions, supported a diverse array of macroalgae, spermatophytes, and macroscopic fauna.

Overall plankton density was higher in the saltpans relative to the open sea. These counts were comparatively high between August to October 2022, declining sharply from November 2022 onward. The frequency of macrofaunal sightings was much higher in the two large reservoirs relative to the open sea and the inner saltpans, with sightings increasing throughout 2023 compared to 2022. The macrofauna within the reservoirs included 27 species of fish, a much higher species density compared to the open sea. The reservoirs were also colonised by various species including the Blue Swimmer Crab (*Portunus armatus*), Mediterranean Stone Crab (*Eriphia verrucosa*), and Upside-Down jellyfish (*Cassiopea andromeda*), in much higher densities than the open sea. The inner saltpans were attractive to avifauna, with 20 species of birds recorded using the saltpans as feeding grounds during the study. The most abundant were gulls (*Larus* spp.) whilst occasional visitors included flamingos (*Phoenicopterus ruber*).

In the case of algae and spermatophytes, the flora of the two large reservoirs was predominantly of marine origin, including *Posidonia oceanica*, *Cymodocea nodosa*, *Ulva* sp., *Halophila stipulacea*, *Cladophora* sp. and *Acetabularia* sp. However, species associated with brackish water, including *Ruppia* sp. were also present in high densities. The innermost saltpans, subjected to extreme conditions such as hypersalinity and high temperatures, supported only a few highly adapted species, including the halophilic algae *Dunaliella salina*.

Discussion

In general, salinas are relatively simplified habitats with definite boundaries and with predictable physico-chemical and ecological gradients. Electrical conductivity generally increases with distance away from the sea and biological diversity decreases along the same spatial axis [3], although not necessarily proportionately [18]. The electrical conductivity gradient in the SSC largely followed this pattern, with increasing concentration of salt along the inland axis. The pH trend was similar, with an abrupt increase in the saltpans relative to the open sea. This trend is less straightforward to explain, as it depends on the chemical composition of the brine [19]. Nitrate and phosphate content showed no clear spatial trend and the relatively high coefficient of variation for each parameter (nitrate: 142.9, phosphate: 289.7) suggests that conditions in individual pans were the most likely cause of any variations. Much of the organic content in individual saltpans was associated with the presence of avifauna, accounting for higher nitrate concentrations in the saltpans used as feeding and resting grounds by birds. The saltpans with higher nitrate content were usually characterised by dinoflagellate blooms during the warmer parts of the year.

In contrast to the physico-chemical characteristics, the general species diversity observed in the SSC may be best represented by a unimodal pattern, with relatively low diversity in the open sea and in the inner saltpans and with much higher species richness in the intervening reservoirs. This pattern is a consequence of the interaction of the chemical conditions and habitat stability in each of the three habitat segments considered (open sea, reservoirs, inner saltpans). The physico-chemical stability is highest in the open sea and reservoirs and lowest in the smallest saltpans and is related to buffering capacity. The small size of the inner saltpans gives them very little buffering capacity against large-scale environmental changes such as storm surges. Two storm surges were observed during the period of study, during which the associated rise in sea level flooded the SSC completely reverting the chemical conditions in the inner saltpans to marine conditions. The larger size of the reservoirs buffered much of this change. Following subsidence of the surges, conditions gradually reverted to those observed previously. These surges were also accompanied by widespread mortality of macrofauna and replacement of the planktonic assemblages with that characteristic of the open sea. The higher species diversity in the two large reservoirs may be explained in terms of their lower physico-chemical variability compared to the open sea and their different EC, providing habitat space for non-marine species adapted to those conditions, and to their function as a 'species trap'. In this case, species present in low densities in the open sea and therefore potentially undetected by occasional surveys, may translocate into the pans and establish a population there. The unbalanced fauna and abundance of food resources would then promote larger populations than those recorded from the specific marine area that was sampled, leading to higher alpha diversities.

Conclusion

The results of this study provide a preliminary foundation on which to base conservation and management strategies for the SSC, taking the adjacent marine environment into account. The primary function of the SSC is that of an ornithological reserve and the prevalent conditions provide the resources required to sustain this function. The elevated species richness in the two reservoirs is attributable to the greater stability of this portion of the habitat relative to the marine environment (in terms of mechanical energy) and the inner pans (in terms of physico-chemical extremes). In conclusion, the findings underscore the importance of considering both internal conditions and the external marine influence to inform effective habitat management strategies. These should focus on maintaining the conditions that support the assemblage of species, in the more stable reservoirs that serve as biodiversity hotspots within the complex.

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USING MULTISPECTRAL UAV IMAGERY AND GROUND TRUTHING TO ASSESS THE SUCCESS OF VEGETATION REINFORCEMENT IN A COASTAL AREA – THE CASE OF INWADAR NATIONAL PARK, MALTA

Leanne Camilleri, Sandro Lanfranco

Abstract: Ground-based methods of vegetation survey are slow and expensive, but recent technological developments have made UAVs (Unoccupied Aerial Vehicles or drones) accessible to consumer budgets, facilitating their use in vegetation monitoring. We propose a method for using UAVs to evaluate a vegetation reinforcement programme in a coastal area in Malta and compare its accuracy and cost-effectiveness with that of ground-based methods (including walkthrough-surveys and measurements of chlorophyll-a content). Multi-seasonal imaging of the site was captured using a DJI Phantom 4 drone equipped with sensors sensitive to visible, near infrared (NIR) and red edge (RE) light. These images were used to construct NDVIs of the site from which vegetation characteristics were deduced. Results suggest that UAVs provides a cost-effective way to map, quantify, and detect changes in vegetation cover which can enable assessment of physiological performance once a calibration procedure has been carried out. With an accuracy comparable to ground-based surveys, but quicker and cheaper, drone-based methods provide a viable and economically-attractive alternative to manual surveying methods.

Keywords: UAVs, vegetation monitoring, reinforcement programme, NDVIs, cost-effectiveness

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Leanne Camilleri, Sandro Lanfranco, Using multispectral UAV imagery and ground truthing to assess the success of vegetation reinforcement in a coastal area – the case of Inwadar National Park, Malta, pp. 112-123, DOI: 10.36253/979-12-215-0556-6.09

Introduction

Vegetation reinforcement, in the context of environmental restoration, refers to the process of reintroducing native or adaptive plant species into degraded or disturbed areas to augment existing plant populations, with the consequent aims of restoring ecological function, increasing population viability, improving soil stability, and enhancing habitat quality [4, 9, 13, 23].

The success of any vegetation reinforcement programme can only be evaluated by comparison with two implicit or explicit benchmarks: the pre-reinforcement phytocoenosis (the starting point) and a reference phytocoenosis that would have been, a priori, defined as the 'target' (or end point) of the reinforcement programme. These comparisons imply the necessity of regular surveys of vegetation before, during, and after the implementation of the reinforcement programme. Frequent vegetation surveys over large areas are labour-intensive and are therefore a slow and expensive process [2, 10, 21].

In this regard the recent emergence of UAVs (Unoccupied Aerial Vehicles) accessible to consumer budgets, has facilitated their utilisation for these purposes. The cost of UAVs has decreased substantially, making them affordable for a broader range of users, including individual researchers, small organisations, and conservation groups. Moreover, consumer-grade drones equipped with high-resolution cameras and GPS capabilities can now be purchased at a fraction of the cost of traditional aerial survey equipment [10]. Additionally, improvements in UAV technology, such as enhanced battery life, increased payload capacity, and advanced sensors (including multispectral, thermal, and LiDAR), have expanded the capabilities of these devices, facilitating the creation of various drone-based approaches [19]. These advancements enable detailed and precise data collection, through real-time, high-resolution, and updated imagery, which can be acquired over large and inaccessible areas, making them a practical and cost-effective solution for vegetation surveys [22].

General Aim

In this study, we propose a workflow for using UAVs to evaluate the results of a pilot vegetation reinforcement programme in a coastal area in Malta and compare its accuracy and cost-effectiveness with that of ground-based methods previously used for assessing the same general area, namely manual vegetation-mapping surveys and measurements of chlorophyll-a content of plant leaves in situ, as a general assessment of 'plant health'.

Materials and Methods

The Area of Study

The pilot programme was carried out in Inwadar National Park (INP), a protected area situated along the south-eastern coast of Malta during the period from 5 January 2023 to 31 May 2024. INP, which covers an area of 0.97 km^2, is designated as a Special Area of Conservation (SAC) of National Importance (Malta Government Legal Notice 162, 2019), and is therefore part of Malta's National Ecological Network. Its land cover is predominantly rural, composed of agricultural parcels, many of which are under active cultivation. The land is terraced along a slope leading down to the shoreline, where natural, fragmented phytocoenoses are present. These mainly consist of a coastal scrubland that is superimposed a ruderal flora characteristic of habitat disturbance. Former agricultural areas that are no longer cultivated are undergoing a secondary ecological succession, creating a continuity between the rural landscape and coastal terrains.

The pilot vegetation reinforcement study was carried out in an 'intervention site' within the northwestern sector of the INP. The site was specifically chosen for its coastal maritime garrigue community, typical of the *Crithmo maritimi-Limonietum virgati* phytosociological association [5]. This association mainly consists of low-lying vegetation with a variety of halophytes and chasmophytes. The intervention site also comprises a small segment of a former agriculture field undergoing a second ecological succession ("old-field" succession), dominated by a xerophilous community with less salt-tolerant species. Margins on the south-west aspect of the site were colonised by a high richness of ruderal species, mainly annuals, grasses and geophytes at the time of survey. The intervention site covers an area of 13486 m^2, with the length of the primary and secondary axes measuring 286 m and 105 m respectively. The coordinates of the approximate centre of the site are 35°52'46" N, 14°33'43" E.

General Workflow

The study consisted of the following broad steps:

i. Initial surveying and mapping of the 'Intervention Site' using a UAV.
ii. Ground-based surveying and mapping of vegetation within the Intervention Site.
iii. Ground-based measurement of chlorophyll-a content of leaves from plants in the Intervention Site.
iv. Introduction of plantlets, representing the first stage of the vegetation reinforcement programme.
v. Repeated surveying of the area and assessment of the introduced plants during different seasons using a UAV.
vi. A brief cost-effectiveness analysis comparing the drone-based and ground-based surveys.

Mapping of the Intervention Site Using UAV

Initial Field Surveys

Multispectral imaging of the terrain in the site of study was carried out using a DJI Phantom 4 drone equipped with sensors sensitive to red, blue, green, near infrared (NIR) and red edge (RE) light and flying at an approximate altitude of 30 m above ground level in a series of 27 transects. The area overflown during this study covered 15900 m^2, with a flight path 1886 m in length, comprising 438 waypoints. The image capture had a front overlap ratio of 80 % and side overlap of 60 %. The constituent images that were used to generate the orthomosaic had a resolution of 1.6 cm/px. The flight path was programmed on DJI GS Pro running on an Apple iPad.

UAV Image Processing

The images captured during each flight were used to construct an orthorectified mosaic of the study area using Agisoft MetaShape Pro v.2.0.1 [1]. Each orthomosaic was subsequently transformed into a false-colour raster image showing the Normalised Difference Vegetation Index (NDVI) for each pixel, indicating which parts of the area of study had a reflective signature consistent with that of chlorophyll-a. The presence of chlorophyll-a in these images was assumed to represent active vegetation, an assumption that was later verified empirically through ground-truthing.

The classic NDVI formula [20] was modified to account for high soil reflectivity in the site of study. This correction was modelled on that proposed by [2], and subsequently fine-tuned iteratively until the maximum distinction between 'vegetation' and 'non-vegetation', taken as modified NDVI = 0, was attained. The modified NDVI was calculated as follows:

$$modified\ NDVI = \frac{NIR - Red}{\left(\left((NIR + Red) + 0.9\right) * 1.9\right)}$$

In the equation above 'Red' represents the intensity value of red-light (wavelength range: 650 nm ± 16 nm) and 'NIR' the intensity value of Near-Infrared light (wavelength range: 840 nm ± 26 nm). The modified NDVI formula changes the range to approximately −0.585 to 0.585, narrowing it compared to the standard NDVI range of −1 to 1. This modification makes NDVI values less sensitive to extreme values of reflectance, stabilising the index against noise or measurement errors in the data.

The raster image was subsequently imported into QGIS v.3.36.3 'Maidenhead' [17], converted to a binary image, vectorised, and all polygons representing vegetation cover filtered and identified. The cumulative area of 'vegetation' polygons was calculated, giving an estimate of the proportionate vegetation cover in the area of study.

This process was repeated three times: on 24 February 2023, 13 October 2023, and 5 April 2024, representing the 'wet season', 'late dry season', and 'late wet season' respectively. The boundaries of the orthomosaic images from which the vegetation cover was derived were kept constant across sampling sessions by anchoring the margins of the area of study to permanent, identifiable landmarks. These three vegetation maps were used as the basis of the drone-based surveys.

Ground-Based Surveys

Verification of Drone-based Vegetation Maps

The three vegetation maps obtained from the drone-based surveys were compared with those generated from a ground-based walkthrough vegetation survey using an ordinal scale to represent vegetation cover.

Association with Meteorological Data

The relation between seasonal variation in plant cover and meteorological factors was investigated by comparing proportionate vegetation cover in each of the three seasons with the values of mean maximum temperature, mean incident solar radiation, and total rainfall during a 15-day period prior to each mapping session. Weather data was obtained from a weather station at the University of Malta, providing temperature, solar radiation, and rainfall data at 30-minute intervals.

Reinforcement Programme at INP

The pilot reinforcement programme that took place within the designated 'intervention site' in INP, was part of a related study [6]. During this study, 60 plantlets were cultured in vitro and translocated into five 2 m x 2 m experimental plots within the site, on 5 January 2023 (during the wet season). The species used for targeted reinforcement were *Jacobaea maritima* subsp. *sicula* N.G.Passal., Peruzzi & Pellegrino, *Limbarda crithmoides* (L.) Dumort. and *Suaeda vera* J.F.Gmel., basing this selection on their association with the climax phytocoenosis of the characteristic *sigmetum* of the site. An equal number of species was planted in each plot.

Measurement of Chlorophyll-a Content

Determination of Chlorophyll-a Content of Translocated Plants *in situ*

The state of 'health' of the translocated plantlets was assessed empirically through the measurement of chlorophyll concentration in the leaves and compared with values from 150 leaves of the same species in other parts of INP. This was done using an Opti-Sciences CCM300 Chlorophyll Content Meter. The instrument measures the ratio between the fluorescence of chlorophyll-at 700 nm and 735 nm and converts these into an estimate of chlorophyll concentration in mg/m² using the equation proposed by [11].

The chlorophyll-a content of each plant in the experimental plots was estimated by selecting three leaves from each plant: one at the apex, one at the base and another in the central segment. Chlorophyll-a measurements for each leaf were recorded as the median value of five repeated readings. This process was first conducted on 31 January 2023, approximately four weeks post-translocation, and subsequently repeated after six and nine weeks. The process was also repeated at the end of the following dry season (22 November 2023) and at the end of the succeeding wet season of 2024 (5 April 2024).

Determination of 'Background' Chlorophyll-a Concentrations

Additionally, the chlorophyll-a content of 150 randomly selected leaves from each of the three target species (*J. maritima*, *L. crithmoides*, and *S. vera*) was measured to provide a comparative estimate of chlorophyll-a concentration in plants that had germinated and developed in situ. These 'comparison' leaves were sourced from plants within a radius of 100 m of the experimental plots to minimise the influence of any confounding factors arising from environmental heterogeneity. These measurements were conducted on 3 February 2023.

Relative Cost of Drone-based and Ground-based Monitoring Methods

The effectiveness of a monitoring programme to evaluate the longer-term effects of vegetation reinforcement is quantifiable in terms of its cost and of the quality of data obtained. The quality of the data of a direct, ground-based survey would always be expected to reflect the 'real' situation more accurately than a remote survey. However, if the quality of the remotely acquired data approximates (if not emulates) that of direct, ground-based methods within an accepted margin of tolerance, then the trade-off would be referred to the relative cost of the methods. The relative cost of a drone-based vegetation monitoring method compared to ground-based walkthrough surveys was estimated by breaking down both workflows ('drone' and 'manual') into a series of steps, based on the authors' direct experience of the process over several years. The steps selected were the following:

i. Purchase of equipment and software (UAV including a sufficient number of battery packs, chlorophyll meter, software licenses).
ii. Cost (in man-hours) of first survey and data processing. For the drone-based method, the first survey would incorporate the drone flight, post-processing of data, and a ground-based survey for the purposes of ground-truthing. For the manual method, this would comprise the time required for the vegetation survey and processing of its data.
iii. Cost (in man-hours) of second and subsequent surveys. For the drone-based method, this would include the drone flight and post-processing whilst for the manual method it would comprise the vegetation survey and data processing.

The cost of the whole process for a realistic monitoring programme was estimated based on four multi-seasonal surveys per year for a period of five years. The area to be monitored was conservatively estimated to be ten times larger in area than that of the intervention site (0.135 km^2; approximately 14 % of the whole area of the INP). Since the cost of equipment was estimated in currency units, this necessitated the conversion of 'man-hours' into currency, a conversion factor that varies considerably across territories. For the purposes of this study a standard man-hour rate of 40 € was utilised, consistent with the expected cost of this expertise in the Maltese job-market. The cumulative cost of the drone-based and ground-based methods was expressed as a cost-effectiveness ratio.

Results

Seasonal Change in Vegetation Coverage

The three false colour orthomosaic images representing the modified-NDVI values in the Intervention Site in three different seasons, are shown in Figure 1. Each image illustrates the vegetation cover and relative intensities of chlorophyll-a (a priori taken to be a proxy for photosynthetic activity). Whilst much of the coastal fringe was characterised by bare rock, plants typical of the coastal community in INP occurred in isolated pockets of soil. The plant assemblages had varying levels of photosynthetic activity (as indicated by the modified-NDVI value), with the confluence of vegetation cover and photosynthetic rates increasing further away from the shoreline. The photosynthetic activity of shallow-water marine algae colonising the lower coralline limestone platform along the shore is also evident.

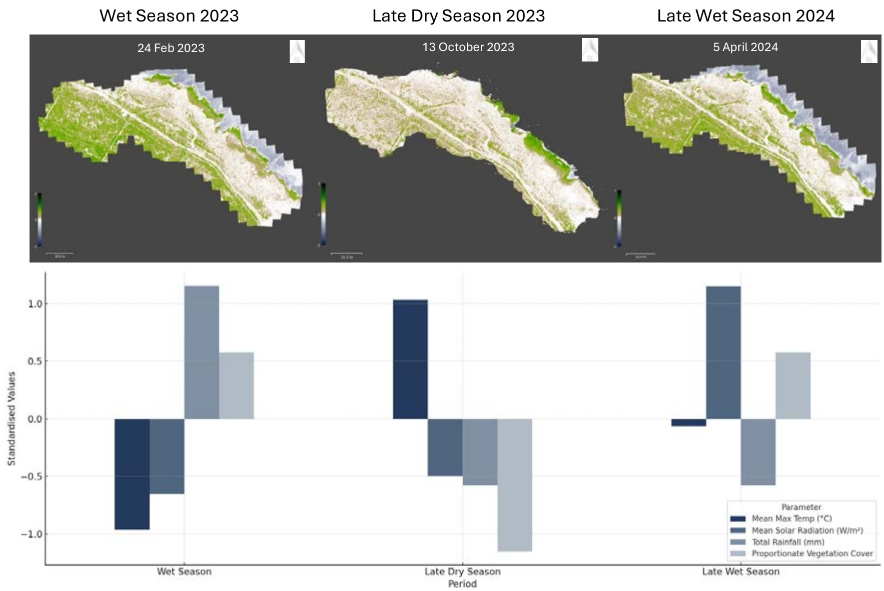

Figure 1 – Variation in vegetation cover in the INP ‘intervention site’ across the duration of the study. These are false-colour images representing the value of the modified-NDVI index in the area of study. The column graphs show the standardised mean maximum temperature, mean incoming solar radiation, total rainfall and proportionate vegetation cover during the 15-day period preceding each mapping date.

Across the different seasons, the change in vegetation cover is noticeable, as can be observed graphically in Figure 1. The fluctuation in vegetation cover was broadly (and predictably) associated with seasonal variation in rainfall, temperature, and incoming solar radiation, all of which are important determinants of rates of photosynthesis. No quantitative measures of association or correlation have been calculated, as the sample size was too small to permit this. Visual inspection of the results based on walkthrough assessments suggested that the outcomes were broadly comparable and certainly within the acceptable margins of error for large-scale vegetation surveys.

Temporal Variation in Chlorophyll-a Content

An overview of the “performance” of the translocated plants in terms of chlorophyll-a content throughout the monitoring programme, for each target species, is shown in Figure 2.

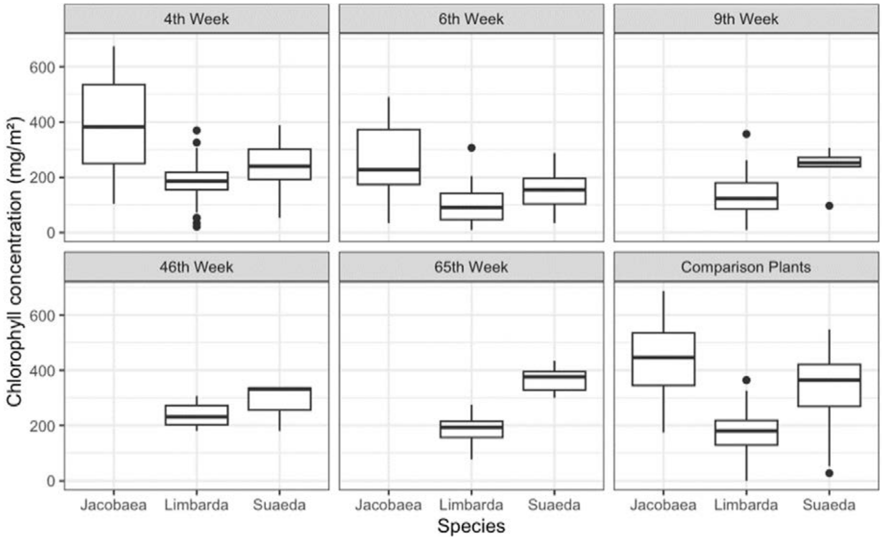

Figure 2 – Chlorophyll concentration (mg/m^2) in the leaves of each of the target species at 4, 6, 9, 46, and 65 weeks post-translocation, and the chlorophyll concentration (mg/m^2) in the leaves of the "Comparison plants" growing in situ. On the x-axis, 'Jacobaea' refers to *Jacobaea maritima* subsp. *sicula*, 'Limbarda' to *Limbarda crithmoides*, and 'Suaeda' to *Suaeda vera*.

A decline in chlorophyll-a content can be noted between the fourth and sixth weeks following translocation, followed by relative stability, where the chlorophyll concentration of the introduced plants was comparable to that of the comparison plants. The relevance of these results to this study are related to their detectability in UAV imagery. The chlorophyll-a concentration of the surviving plants in the reinforcement programme is approximately equivalent to that of the comparison plants after one year following translocation. Following a suitable calibration procedure relating chlorophyll a content to specific NDVI patterns (which was not the scope of the present study), the multispectral imagery would potentially provide information that is not limited to the extent of vegetation cover, but also the broad physiological performance of the introduced plants.

Relative Cost-effectiveness of Methods

The cumulative cost of drone-based and ground-based methods evaluation of the results of the reinforcement programme, based on a 40 € man-hour rate and a five-year multi-seasonal monitoring programme on an area ten times that of the intervention site, are shown in Figure 3A. These estimates suggest that after four sessions (one calendar year), the cumulative cost of both methods is approximately equal. By the end of the five-year monitoring programme, the total cost of the drone survey is approximately 53 % that of the ground-based manual surveys. Even if wide margins of error are allowed for, these results suggest that the drone-based method is far quicker, and therefore much less expensive, than the ground-based method. The ongoing cost difference between the drone-based and ground-based methods is summarised in Figure 3B.

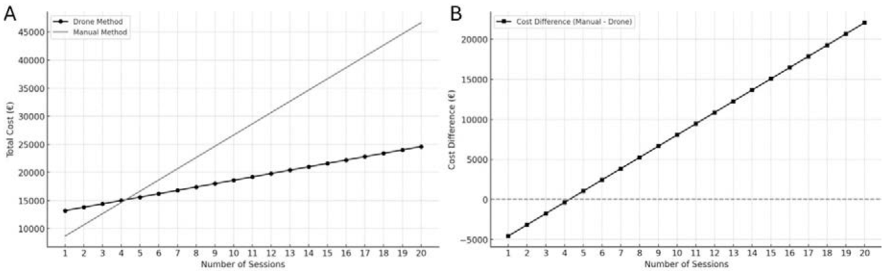

Figure 3 – Comparison of the cumulative cost of drone-based and ground-based survey methods, based on a man-hour rate of 40 €, over a five-year period (20 sessions). B. Ongoing difference in cost between ground-based ('manual') and drone-based methods of survey over a duration of five years (20 sessions).

Discussion

Cost Differentials

The preliminary results obtained during this study suggest that the use of UAVs to map vegetation cover using multispectral imagery gave results that were detailed enough for the intended purpose, whilst being achieved in a much shorter time period, and therefore, at lower cost, than ground-based methods. Naturally, there are other factors that need to be taken into consideration in an overall assessment. The role of meteorological factors neds to be considered in more detail. Rainy and windy conditions that would not impair a ground-based survey may render a drone flight risky. Similarly, if a study site is situated in a no-fly zone, this would make the method unfeasible. However, away from these outlier conditions, the results may be generalised to support a more widespread and economically viable use of UAVs in mapping the physiological condition of vegetation.

Sensitivity to Changes in Vegetation Cover

The multispectral imagery was able to provide very clear indications of the change in cover across seasons, in theory, down to the centimetre scale. In practice, the modified-NDVI image is an approximation of the 'real vegetation' and is dependent on the effectiveness of the raster transformation in recognising scales of reflectivity and on the ability of simple filters to make a binary distinction between vegetation and non-vegetation pixels in the vectorised images.

The preliminary results were also able to demonstrate that the relationship between meteorological conditions and vegetation cover is not a linear one. As a case in point, in February 2023 and April 2024, the vegetation cover was not very different even though the rainfall differed considerably, suggesting that adaptations of vegetation to dry conditions may be more important predictors of vegetation cover.

Nonetheless, this data was collected over a relatively short period of time and while it might be adequate to generate a benchmark for a pre-reinforcement phytocoenosis, long-term monitoring is required to assess the success of a reinforcement programme and allow for the implementation of adaptive management. Understanding these patterns can help in developing strategies for climate resilience, e.g. introducing drought-resistant plant species or implementing water conservation measures to mitigate the adverse effects of the dry seasons.

Importance of Chlorophyll Concentration

In general, chlorophyll content is expected to follow a general trend of initial variability and possible decline due to transplant shock [14], environmental stressors, plantlets still developing an extensive root system for optimal nutrient and water uptake [8], or not having yet adjusted to the new soil microbiome [12]. Subsequently, the chlorophyll-a content in the leaves of plants stabilises and increases, reaching a saturation point as the plants become fully acclimatised and benefit from optimal growing condition. This trend was observed in this study. Additionally, seasonal changes are also expected to impact chlorophyll levels, with lower content during dry periods and higher content during wet seasons. Eventually a season with peak photosynthetic activity is expected to be reached, generally during or post-wet season [3, 15].

Empirical assessment of re-introduced plants through the measurement of chlorophyll concentration in the leaf is considered a reliable indicator of general plant health. Chlorophyll content is directly linked to the photosynthetic capacity of plants, as it is the primary pigment involved in capturing light energy. High chlorophyll levels generally correlate with better plant vigour, productivity, and overall health. Thus, measuring chlorophyll concentration can help identify nutrient deficiencies and stress factors in plants, and chlorophyl reading methods have been employed in several studies with diverse contexts [7, 16, 18]. Moreover, the chlorophyll content is species dependent and can fluctuate dynamically with the age of the leaves, light exposure, environmental conditions and seasonal changes [3, 15].

Knowledge of the chlorophyll-a content of individual species may permit the correlation of the modified-NDVI regions with actual chlorophyll-a values, facilitating large scale assessment of the physiological performance of introduced plants in a short period of time. This study has not attempted that step but has provided data that may be used to construct a specific workflow for that purpose. It is interesting to note that the variability in chlorophyll content of the leaves in the comparison sample was higher than that recorded from the experimental plots. While this may be attributable to the difference in sample size, it could also be a result of stress that plants within the experimental plots may have been subjected to and that was not controlled for. The chlorophyll-a content of perennial species across seasons also varied synchronously with the observed modified-NDVI values, suggesting that the latter can be used as a broad proxy for the former if a specific calibration curve is constructed.

Conclusion

The general conclusion of this study is that the use of UAVs provides a cost-effective way to map, quantify and detect changes in vegetation cover and, in broad terms, to assess the physiological performance once a calibration procedure has been carried out. However, whilst providing effective methods by reducing time expenditure and capturing real-time representations of landscapes, the use of UAVs needs to be implemented with careful planning and consideration of project-specific goals so as to achieve their maximum successful integration in a vegetation reinforcement programme.

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ENVIRONMENTAL ISSUES AFFECTING LOGGERHEAD TURTLES *CARETTA CARETTA*: A STUDY ON THE PRESENCE OF INORGANIC POLLUTANTS IN ORGANS, TISSUES, AND EGGS

Silvia Canzanella, Angela Pepe, Doriana Iaccarino, Domenico Ricupero, Ludovica Curcio, Emanuele Esposito, Giuseppe Picazio, Fulvio Maffucci, Fabio Di Nocera, Giuseppe Lucifora, Pasquale Gallo, Mauro Esposito

Abstract: Climate change significantly impacts nesting areas for sea turtles, leading to an expansion in the Western Mediterranean regions, particularly along the southern Italian beaches, in recent years. Furthermore, along these coasts, there is intense activity in recovering stranded turtles.

Within the One Health approach, which integrates health and environment, there is increasing interest in monitoring marine pollution and its effects on loggerhead turtles.

Caretta caretta (L., 1758), the most abundant sea turtle in the Mediterranean Sea, is globally categorized as "vulnerable" among endangered species. Due to their wide-ranging migrations, for extended periods, on a large geographical scale, sea turtles can accumulate marine pollutants including metals, PCBs, pesticides, PAHs and PFAS, in their liver, kidneys, and adipose tissue. Upon attaining sexual maturity, these toxicants may be transferred to offspring through the eggs, thus exposing developing embryos to potentially high doses of pollutants. This study aimed to quantify inorganic chemical contaminants in organs, tissues, and eggs of *C. caretta*.

Keywords: threatened species, marine environment, sea turtle, *Caretta caretta*

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

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Introduction

In the context of the One Health approach, which integrates human, animal, and environmental health, there is growing interest in monitoring marine pollution and its impacts on marine organisms.

Loggerhead turtle *Caretta caretta* (Linnaeus, 1758), the most abundant marine turtle species in the Mediterranean Sea, is globally classified as "vulnerable" on the International Union for Conservation of Nature's Red List of Threatened Species [2]. This species faces significant threats from high levels of anthropogenic activities in coastal areas, maritime traffic, macroscopic (plastic and other waste) and chemical pollution, fishing practices, as well as the ingestion of hooks and lines [16].

Since loggerhead turtles are omnivorous, consuming a diet rich in cephalopods, jellyfish, algae, and mollusks, they can accumulate high levels of contaminants, including metals [3,6]. This capability makes them excellent sentinel animals and bioindicators for monitoring marine water quality.

The 2008/56/EC Marine Strategy Framework Directive [7] established that the marine environment, a precious heritage, must be protected, safeguarded, and, where possible, restored. The aim is to maintain biodiversity and preserve the biodiversity and vitality of seas and oceans, ensuring they remain clean, healthy, and productive.

To achieve the objectives set by this Directive, it is necessary to consider the descriptors outlined in the Decision, including the need to maintain the contaminant concentrations at levels that do not result in pollution effects.

Toxic elements, such as mercury, lead, and cadmium, derived from both natural sources and widespread use in agriculture and industry, are pervasive in aquatic ecosystems [1].

These non-essential elements, also known as heavy metals, are particularly concerning due to their well-documented toxic effects on marine animals, including sea turtle [3].

Other inorganic elements such as arsenic, chromium, copper, manganese, nickel, selenium and zinc are found globally in aquatic systems and their potential transfer to marine turtles could pose a threat to their health [8]. Many of these elements are essential, but they can become toxic if their concentrations exceed certain values. Studies have shown carcinogenic and teratogenic effects, as well as toxicity to the neural, renal, reproductive and endocrine systems in sea turtles [19]. Additionally, positive correlations have been observed between some trace element concentrations and hatching success *Caretta caretta* nests [17].

Due to their peculiar ethological characteristics, longevity, feeding ecology, habitat use and migratory nature, sea turtles are considered good sentinel species for environmental assessment [15] and has been proposed as an indicator for Good Environmental Status (GES) to improve the effectiveness of conservation strategies [11].

Several studies have determined the levels of heavy metals, notably cadmium and lead, in various tissues of sea turtles. However, data on mercury are less common, despite its high toxic significant presence in the Mediterranean. Since the industrial Revolution, the Mediterranean Sea has received substantial amounts of mercury, which accumulates in sediments, water and biota. As a semi-enclosed basin, it has limited water exchange with the Atlantic Ocean, insufficient to dilute the high quantities of mercury discharged into it [5]. Finally, the low number of studies on mercury levels in turtles can be attributed to the specific analytical requirements for its determination [4].

Studies on the presence of potentially toxic elements in the tissues of sea turtles in the Western Mediterranean Sea are limited [1,8]. This lack of data is even more acute for turtle eggs, although climate change is leading to increased nesting activity along the western coasts of the Mediterranean [12].

Eggs also represent a valuable and sensitive biomarker that can indicate the body burden of sea turtles resulting from their exposure to various chemicals, while simultaneously minimizing the impact of tissue sampling on live specimens [14]. In this paper, we report the levels of trace element in the liver, muscle tissue, and eggs of *Caretta caretta* turtles from the Western Mediterranean Sea.

Material and Methods

In 2022, 26 loggerhead turtles were found stranded on the beaches of Campania region in Southern Italy. Twenty-four carcasses, which showed no evidence of decomposition, were subjected to necropsy and biometric parameters were recorded. Length parameters, including straight line carapace length (SCL), curved carapace length (CCL), straight line width (SCW), curved carapace width (CCW), head width (HW) and curved plastron length (CPL), were measured to the nearest 1 cm using a flexible tape measure. Sex determination was carried out by visual examination of the gonads and in case of doubt, confirmed by histological examination. Liver and muscle tissue were collected and kept frozen at -20°C until analysis. The yolk and albumen samples were obtained from unhatched eggs collected from 20 nests located along the beaches of the Campania region in Southern Italy (Figure 1). A single unhatched egg was taken from each of the 20 nests located in Campania, and analyses were carried out on the albumen and yolk separately.

For the determination of trace elements, 0.5 g of homogenized samples of liver, muscle tissue and egg content (albumen and yolk) were weighed and subjected to acid mineralization with 5.0 mL of 70 % nitric acid for trace element analysis, 2.5 mL of 30% hydrogen peroxide, and 2.5 mL of ultrapure water using a microwave digestion system ultraWAVE (Milestone, Bergamo, Italy) following a modified EPA Method 200.8 (US EPA, 1994) and EPA Method 3051A (US EPA, 2007). After digestion, the sample was brought to room temperature and then diluted with ultrapure water. Trace elements were analyzed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) mod. NexION 350X (Perkin Elmer, Waltham, MA, USA). Standard solution containing arsenic (As), cadmium (Cd), cobalt (Co), copper (Cu), chromium (Cr), iron (Fe), lead (Pb), manganese (Mn), nickel (Ni), selenium (Se), strontium (Sr) and zinc (Zn) at 1000 mg L^{-1} (Perkin Elmer, Waltham, MA, USA) was used to obtain calibration curves. Standard solution of rhodium as internal standard at a concentration of 200 ng mL^{-1} was added to standard and sample solutions by means of online mixing.

Total mercury (Hg tot) was determined using the gold amalgamation combustion atomic absorption spectrometry technique with a Direct Mercury Analyzer® DMA 80 evo (Milestone, Sorisole, Italy).

Figure 1 – Nests and stranding sites of the loggerhead turtles *Caretta caretta* in 2022.

For the analysis, 100 mg of homogenized sample was weighed directly into nickel boats and transferred to DMA. Total mercury concentrations were calculated by interpolation of absorbance (λ = 253.7 nm) in external analytical curves obtained by analysis of solutions of mercury at different concentrations (0.005, 0.010, 0.025, 0.050, 0.100, 0.200, 1.0 mg L^{-1}) prepared by dilution with ultrapure water of a 1000 ± 2 mg L^{-1} standard solution of inorganic mercury (Merck KGaA, Darmstadt, Germany).

Mussel tissue ERM®- CE278k (Joint Research Centre, Belgium) was used as a certified reference material (CRM) for validation of method (assessment of trueness and repeatability) and quality assurance.

Results

A total of 24 specimens of *Caretta caretta* (12 females, 10 males, 2 non determined) found stranded in 2022 along the coast of the Campania region in Southern Italy were analyzed in this study. The measured biometric parameters are reported in Table 1.

Table 1 – biometric parameters (cm) measured in 24 *Caretta caretta* specimens from Campania region.

	Mean	***SD***	***Median***	***Min***	***Max***
SCL	58.4	16.3	66.1	27.5	82.6
CCL	62.4	16.2	69.0	31.0	88.0
SCW	45.5	11.8	49.4	23.7	62.8
CCW	57.3	15.5	62.5	28.0	80.0
HW	11.0	2.9	11.5	6.2	15.7
CPL	44.6	11.1	50.8	24.0	56.5

The body weight of the turtles ranged from 3.8 kg to 75.0 kg with a mean value of 31.4 kg. Regarding age, 10 specimens were classified as juveniles and 14 as adults.

During 2022, a total of 20 unhatched eggs from nests located along the beaches of Campania region were collected, and the content (yolk and albumen) analysed for the levels of trace elements.

The characteristics of the nests sampled are reported in Table 2, including municipality, geographic coordinates (latitude and longitude), clutch size (number of eggs laid), Hatching Success (HS%), which is the percentage of eggs that successfully hatch into hatchlings out of the total number of eggs laid, and Emerging Success ES%, which indicates the proportion of hatchlings that emerge from the nest chamber and reach the surface of the beach. As usually happens, ES% (mean value 70 %) is slightly lower than HS% (mean value 75 %) because not all hatchlings reach the beach surface.

The results (mean value, standard deviation, min and max) of the determination of trace element concentrations in albumen, yolk, muscle tissue and liver are reported in Table 3.

Table 2 – Characteristics of nests sampled for the study: municipality, latitude and longitude, clutch size, HS% (Hatching Success) and ES% (Emerging Success).

Nest	*Municipality*	*Lat.*	*Long.*	*Clutch size*	*HS %*	*ES %*
N02	Camerota	40.00085	15.38069	95	58.9	58.9
N03	Eboli	40.5462	14.907	129	69	65.9
N04	Castel Volturno	40.89958	14.03233	82	81.7	81.7
N05	Camerota	40.02963	15.31913	123	90.2	84.6
N06	Camerota	40.00075	15.38092	92	21.7	20.7
N07	Castel Volturno	40.93824	14.00989	63	93.7	71.4
N08	Eboli	40.51271	14.92557	96	86.5	75
N09	Camerota	40.02896	15.32028	77	98.7	98.7
N10	Camerota	40.02594	15.32345	112	50.9	50
N11	Castel Volturno	40.99533	13.9577	74	50	41.9
N12	Acciaroli	40.19066	15.02087	105	22.9	22.9
N13	Centola	40.04788	15.28393	100	89	87
N14	Castel Volturno	40.93573	14.01151	53	79.2	77.4
N15	Eboli	40.54536	14.90767	101	92.1	65.3
N16	Camerota	40.02658	15.32308	72	97.2	97.2
N18	Camerota	40.02012	15.32881	97	71.1	57.7
N19	Pollica	40.18484	15.0242	60	93.3	93.3
N20	Camerota	40.00013	15.38468	81	91.4	85.2
N21	Centola	40.04801	15.28397	88	92	92
N23	Centola	40.04899	15.28349	77	81.8	57.1

Table 3 – trace element concentrations (mean ± sd in mg kg^{-1}, range min-max) in muscle tissue, liver, yolk, and albumen of eggs of loggerhead turtles.

	Albumen	***Yolk***	***Muscle***	***Liver***
	mean ± sd (min-max)	**mean ± sd** (min-max)	**mean ± sd** (min-max)	**mean ± sd** (min-max)
As	**0.220 ± 0.125** (0.035-0.401)	**0.904 ± 0.606** (0.183-2.11)	**21.05 ± 14.3** (3.29-68.0)	**8.55 ± 4.81** (1.27-20.1)
Cd	< LOQ	**0.005 ± 0.003** (0.001-0.008)	**0.026 ± 0.028** (0.001-0.129)	**1.35 ± 0.63** (0.53-3.18)
Co	**0.007 ± 0.002** (0.004-0.014)	**0.013 ± 0.002** (0.011-0.016)	**0.020 ± 0.032** (0.003-0.127)	**0.041 ± 0.042** (0.015-0.201)
Cr	**0.297 ± 0.254** (0.049-0.880)	**0.311 ± 0.202** (0.107-0.801)	**0.369 ± 0.369** (0.029-1.30)	**0.110 ± 0.109** (0.019-0.51)
Cu	**0.974 ± 0.961** (0.053-3.04)	**1.46 ± 0.546** (0.688-3.0)	**0.743 ± 0.373** (0.385-1.92)	**8.51 ± 5.73** (1.61-23.0)
Fe	**3.56 ± 1.78** (0.859-6.75)	**20.2 ± 5.5** (12.0-31.8)	**45.2 ± 56.9** (8.6-229)	**461.7 ± 418.2** (59-2003)
Hg	< LOQ	**0.022 ± 0.014** (0.011-0.060)	**0.067 ± 0.028** (0.023-0.160)	**0.243 ± 0.162** (0.070-0.801)
Mn	**0.077 ± 0.044** (0.026-0.159)	**0.530 ± 0.283** (0.226-1.34)	**1.38 ± 2.45** (0.06-9.30)	**3.32 ± 8.80** (0.51-44.5)
Ni	**0.175 ± 0.145** (0.034-0.512)	**0.172 ± 0.113** (0.054-0.447)	**0.156 ± 0.184** (0.014-0.655)	**0.060 ± 0.044** (0.021-0.196)
Pb	**0.016 ± 0.008** (0.007-0.032)	**0.040 ± 0.012** (0.024-0.061)	**0.054 ± 0.047** (0.014-0.223)	**0.080 ± 0.061** (0.022-0.123)
Se	**0.282 ± 0.183** (0.038-0.585)	**1.15 ± 0.40** (0.30-1.72)	**1.38 ± 0.52** (0.36-2.31)	**3.45 ± 1.88** (1.20-9.28)
Sr	**5.06 ± 2.41** (1.00-8.86)	**38.6 ± 10.9** (17.2-59.1)	**2.35 ± 1.21** (0.61-5.25)	**16.1 ± 28.3** (1.17-99.0)
Zn	**3.93 ± 3.93** (13.6-0.15)	**31.1 ± 26.2** (8.7-137.3)	**18.0 ± 8.7** (8.8-38.5)	**18.4 ± 6.6** (11.2-37.7)

LOQ: limit of quantification.

Discussion

The loggerhead turtles stranded on the beaches of Southern Italy showed levels of toxic elements similar to those found in previous studies, although a slight decrease in levels should be noted. The most abundant metals in eggs are strontium, zinc and iron, as already reported by Esposito et al. [9]. Compared to the albumen, the yolk contains over 80 % of these elements. This distribution has also been observed for other elements, such as arsenic and manganese. On the other hand, for toxic elements such as nickel and chromium, there is an almost equal distribution in the two matrices of the egg. The interesting result is the low mean level of two toxic metals, lead and mercury, in the yolk (0.040 and 0.022 mg kg^{-1}, respectively) but especially in the albumen (0.016 and <0.001 mg kg^{-1}, respectively).

The average concentration of arsenic in the yolk is similar to that determined in our previous study on whole eggs collected on the coasts of southern Italy [9] while on muscle and liver, values lower than those reported for loggerhead turtle from Mediterranean Sea were detected [1,4,13].

Copper and zinc are two essential elements involved in enzymatic activities, transport processes, and energy production, as well as for egg formation. A study has highlighted how the hatching success of *Caretta caretta* is influenced by their concentrations [17]. In our study, copper levels in the yolk are slightly higher than those in the egg white, while for zinc the concentrations in the yolk are approximately ten times higher than in the albumen (31.1 vs 3.93 mg kg^{-1}). Cobalt plays a fundamental role in many biological processes; at high levels it has been recognized as a possible carcinogen (group 2B) for humans. Low levels of cobalt were recorded in all matrices analyzed.

In the liver, similar to what was observed in eggs, the most abundant metals are iron, zinc, and strontium, followed by arsenic and copper. The presence of cadmium is also relevant (1.35 mg kg^{-1}) in liver which is confirmed to be the one of target organ for the accumulation of this element. The values found are in agreement with those reported by other studies although a slight decrease in levels should be noted [10,18,19]. However, the measured concentrations indicate long term exposure to cadmium but at the same time they highlight a decrease in hepatic cadmium concentration which is lower than all previous studies.

As mentioned above, data on the presence of mercury in *Caretta caretta* turtles from Mediterranean Sea is very scarce, however, compared to the value of 0.26 mg kg^{-1} recorded in turtles stranded between 2014 and 2020 in southern Italy [1] the value of 0.24 mg kg^{-1} determined in this study in the same area on stranded specimens in 2022, appears slightly lower. This decrease is even more evident when compared with the study of Storelli which found in 2003, a value of 0.43 mg kg^{-1} of mercury in the liver [18].

According to the results, nickel had the lowest concentration in the liver compared to other studies on loggerhead turtle [3,10,19], while comparisons for selenium and chromium are more difficult due to lack of data. Manganese plays a fundamental role in biochemical processes; in our study, the levels in the muscle are similar to the values reported in *C. caretta* from Cyprus (1.38 vs 1.402 mg kg^{-1}) but in the liver, the concentration of manganese is much lower than that recorded in the Eastern Mediterranean and the Adriatic Sea (1.53 vs 7.999 and 6.23 mg kg^{-1}, respectively) [3,18].

Conclusion

In this study, different tissues and organs of *C. Caretta* were analyzed to determine the levels of toxic and potentially toxic elements.

The results still showed high values of cadmium and mercury, particularly in the target organ liver, where these metals accumulate and can pose a health risk to these animals. The presence of trace elements in the eggs confirms that metals accumulated in the females are transferred to the eggs.

The results of this study enrich the limited database of inorganic contaminants available for the *Caretta caretta* species in the Mediterranean Sea. On the other hand, they allowed us to compare the concentrations obtained from previous studies and to verify that, in some cases, there was a significant decrease in metals considered toxic, which could reflect a decrease in contamination of the Mediterranean Sea.

Acknowledgements

This study was funded by the Italian Ministry of Health under project IZSME RC 07/22: "The *Caretta caretta* turtle; Sentinel of marine ecosystem health—A study on the correlations between environmental, microbiological, and chemical risk factors". Work on the nesting beach was supported through IN.F.E.A. funds provided by the U.O.D. 50.06.07 of the Regione Campania.

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ENHANCING BIODIVERSITY MONITORING IN MEDITERRANEAN MPAs: eDNA AND STRATEGIC SOLUTIONS

Ginevra Capurso, Kathryn A. Stewart

Abstract: Marine Protected Areas (MPAs) are essential for conserving marine biodiversity and ensuring the sustainability of marine ecosystems. This study examines the current management and monitoring practices within the Mediterranean Sea. Utilizing a questionnaire distributed to 93 MPA managers, we received 29 complete responses, providing insights into the governance, management plans, and monitoring strategies employed across the region. Our findings reveal significant variability in the implementation of management plans, with 48 % of respondents reporting full implementation and 41 % employing ad hoc monitoring strategies. Traditional monitoring methods, such as visual censuses, remain prevalent, while 28 % of respondents reported using eDNA metabarcoding as an additional tool. The integration of eDNA metabarcoding has shown substantial potential in enhancing the accuracy and efficiency of biodiversity monitoring, particularly in detecting species diversity and invasive species. Despite these advancements, challenges persist, including funding constraints, lack of human resources, and inadequate data-sharing practices. To address these issues, we recommend increasing funding, standardizing monitoring protocols, enhancing regional cooperation, and promoting adaptive management informed by robust monitoring data. This study underscores the transformative potential of eDNA metabarcoding in MPA management and highlights the need for strategic improvements to ensure the sustainability and ecological health of Mediterranean MPAs.

Keywords: Marine Protected Areas (MPAs), eDNA metabarcoding, Mediterranean, Biodiversity monitoring, Management strategies

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Ginevra Capurso, Kathryn A. Stewart, *Enhancing Biodiversity Monitoring in Mediterranean MPAs: eDNA and Strategic Solutions*, pp. 134-143, DOI: 10.36253/979-12-215-0556-6.11

Introduction

Marine Protected Areas (MPAs) play a critical role in conserving marine biodiversity, safeguarding habitats, and ensuring the sustainability of marine resources [1]. The MedPAN network, encompassing over 100 organizations across 21 Mediterranean countries, is dedicated to enhancing the effectiveness and connectivity of MPAs in the region. Despite significant efforts, MPAs face numerous challenges, including inconsistent management practices, limited resources, and fragmented monitoring strategies [1]

Effective monitoring is fundamental to the success of MPAs, providing the data needed to inform management decisions, assess the health of marine ecosystems, and adaptively manage conservation efforts. Traditional monitoring methods, such as visual censuses, have been widely used but often fall short in capturing the full spectrum of marine biodiversity, especially for elusive or rare species [2].

Emerging technologies, such as environmental DNA (eDNA) metabarcoding, offer promising advancements in biodiversity monitoring. eDNA involves collecting and analyzing genetic material from environmental samples, providing a non-invasive, efficient, and comprehensive approach to detecting species presence and abundance [3]. This study builds on the findings of Capurso et al. [4], which assessed the utility of eDNA metabarcoding for MPAs. The research aims to evaluate the current management and monitoring status of Mediterranean MPAs, assess the application and potential of eDNA, and identify gaps and opportunities for enhancing MPA monitoring frameworks within the MedPAN network.

Materials and methods

This research builds upon that of Capurso et al. [4], which systematically reviewed the literature and conducted a SWOT analysis to evaluate the effectiveness of eDNA metabarcoding as a monitoring tool for MPAs, highlighting its benefits and limitations in marine ecosystems.

To assess the current management and monitoring status of MPAs in the Mediterranean, the extent of eDNA usage, and the requirements for developing an improved monitoring framework and regional network, we designed and disseminated a comprehensive questionnaire.

The target respondents comprised MPA managers within the MedPAN network, which supports a sustainable, ecologically representative, and well-defined network of MPAs in the Mediterranean. MedPAN includes 127 organizations from 21 Mediterranean countries, but for this study, only members from EU nations were contacted: Croatia, Cyprus, France, Greece, Italy, Slovenia, Spain, and Malta. These individuals are referred to as MPA managers throughout this research.

The anonymous questionnaire was crafted using Qualtrics (www.qualtrics.com) and administered between May and June 2022. It drew inspiration from existing methodologies for evaluating MPA management effectiveness [5, 6]. The questionnaire was structured into four sections, incorporating both multiple-choice and open-ended questions:

i. Details about the organization, including the country of origin, organizational category, geographical scale of operation, and the type of designation of the MPAs managed;
ii. Information regarding the existence, implementation status, and scope of management plans within the MPAs;
iii. Insights into the adopted monitoring strategies, primary tools used, inclusion of eDNA metabarcoding, perceived efficiency of these strategies, and identified limitations;
iv. Assessment of the Mediterranean MPA network's functionality, including the comparability of monitoring strategies, data sharing practices, collaboration among MPA managers, and network gaps and limitations.

The questionnaire was distributed to 93 MPA managers affiliated with the MedPAN network between May and June 2022. Responses were collected and analyzed to determine the current state of MPA management and monitoring, the utilization of eDNA metabarcoding, and to identify areas for improvement in the regional monitoring framework and network collaboration.

By systematically gathering and analyzing this data, the study aimed to provide actionable insights for enhancing the management and monitoring of MPAs in the Mediterranean, leveraging innovative tools like eDNA metabarcoding to address existing challenges and improve overall efficacy.

Results

Overview of Marine Protected Areas part of the MedPAN network

From the 93 organizations contacted, we received 56 responses to our questionnaire resulting in a response rate of 60 %. After excluding incomplete and duplicate responses, the final dataset comprised 29 analysed responses.

The majority of the organizations (52 %) were from the national government administration, including public institutions, agencies and specific MPA managers. This group was mainly represented by Italy, Croatia, and Greece, followed by Cyprus and Spain. The second largest group, representing 24 % of respondents, included organizations from Italy, Croatia, France, and Spain that operated at regional or municipal levels. Non-governmental organizations (NGOs) made up 17 % of the respondents, with representation from France, Italy, and Slovenia. The least represented group, comprising 7 % of respondents, consisted of research and scientific organizations from Greece and Cyprus. Concerning the geographical scale of operations, most organizations (59 %) operated primarily at the local level. A smaller proportion (20 %) operated at the national level, with fewer organizations operating at supra-national levels, such as sub-regional seas networks, Mediterranean, and European scales.

Regarding the type of designation of MPAs, 43 % of organizations operated in MPAs with multiple designations, combining Natura 2000 sites and nationally designated areas. Another 21 % worked in MPAs with only national designations, mostly in Italy, France, and Spain. Additionally, 25 % are involved with MPAs that are part of the Natura 2000 network, primarily in Croatia, France, Greece, and Spain. A minority of 11 % of organizations did not operate with specific designations.

Management of Marine Protected Areas part of the MedPAN network

A minority of respondents (11 %) reported the absence of management plans in their areas of competence, while 17 % had plans that were not implemented. Among the remaining respondents, 24 % indicated partial implementation of management plans, and 48 % reported full implementation. Full or partial implementation was mainly seen in organizations managing MPAs with either national or combined designations. Notably, all organizations in France reported full implementation, followed by Slovenia and Spain, where implementation was partial. In contrast, Croatia and Greece are more frequently characterized by a lack of management plans or their implementation. See Figure 1.

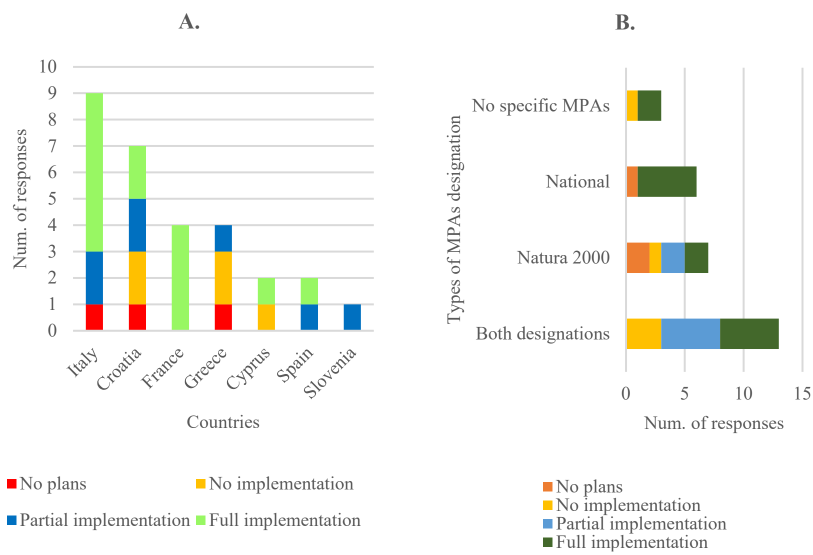

Figure 1 – Management plans of MPAs per country (A.) and Management plans of MPAs classified per type of designation (B.) (n=29).

Monitoring of Marine Protected Areas part of the MedPAN network

Most of respondents reported that there was monitoring in the MPAs of their competence, with only two respondents, from Croatia and Greece, declaring that no monitoring activity was taking place. While 41 % did not have an overarching strategy or systematic collection of results and instead conducted ad hoc monitoring and evaluation, 38 % reported having a well-implemented monitoring and evaluation system used in adaptive management. These structured monitoring strategies were predominantly reported by organizations operating MPAs with national or combined designations. Adaptive management based on monitoring was notably absent in Greece and Slovenia.

In terms of monitoring tools, 69 % of respondents reported using visual census as the primary monitoring tool. Additionally, 28 % used eDNA metabarcoding, primarily for monitoring species diversity and detecting protected or invasive species. All managers using eDNA approaches (28 %) considered their monitoring strategy efficient, though they acknowledge room for improvement. Conversely, more significant limitations in the monitoring efforts were reported by those not using eDNA methods (14 %). Respondents using eDNA generally report better performance, with the majority (5 out of 8 respondents) indicating full implementation of management plans and robust monitoring and evaluation systems.

Gaps and limitations identified by MPAs managers part of the MedPAN network

The monitoring strategy and the Mediterranean MPAs network were evaluated based on respondents' perceptions concerning the comparability of monitoring methods, cooperation, and data-sharing among MPA managers. Most respondents reported that monitoring methods were either partially (59 %) or fully comparable (30 %), with some (38 %) or substantial (45 %) cooperation among managers. However, only 27 % had implemented data-sharing procedures, while 24 % do not implement them, and 21 % lacked available procedures.

Comparing the answers of respondents that used eDNA as monitoring tool to those that did not, some significant differences were observed. Firstly, l of MedPAN survey responders that do not use eDNA methods, there was a significantly higher proportion ($z=-2.27$, $df=13$, $p=0.023$) that also report no data sharing within the network ($n=10$) to those that do ($n=4$), regardless of whether available procedures are in place (see Table 1). Moreover, of respondents that did not use eDNA methods and also shared no data (or don't know if they share data) ($n=13$ of 17), the proportion is even more significant ($z=-3.087$, $df=16$, $p=0.002$). Conversely, there was no significant difference for responders that did use eDNA methods for biomonitoring in their data sharing approach ($n=3$ data share, $n=3$ no data share).

Table 1 – Comparison of answers received from MPAs managers that use eDNA and those that do not on data-sharing practices (n=24).

	eDNA users	Non-eDNA users
Procedures & sharing	3	4
Procedure & no sharing	2	5
No procedure & no sharing	1	5
Don't know	1	3

Secondly, diving deeper into the level of cooperation among MPAs managers, the proportion of those respondents that did not use eDNA methods self-reported significantly less cooperation among the MedPAN MPA network (z=1.7889, df=23, p=0.073; one-tailed test). Combining the respondents that reported “some cooperation” and “little to no cooperation” together, the comparison between eDNA users to non-eDNA users demonstrated a significantly higher proportion of non-eDNA users that reported some to little cooperation among MPAs (z= 1.62, df=23, p=0.053; one-tailed test). See Table 2.

Table 2 – Comparison of answers received from MPAs managers that use eDNA and those that do not on cooperation practices (n=24).

	eDNA users	**Non-eDNA users**
Substantial cooperation	4	7
Some cooperation	4	6
No/little cooperation	0	3

The most common limitation identified by MPA managers regarding monitoring strategies concerned funding constraints (11 out of 29 respondents). These were followed by a lack of human resources (6 out of 29) challenges in data gathering (6 out of 29), including the need to gather data that are still unknown, such as the life cycle of exploited species and the socio-economic impacts of MPAs. Additional concerns included a lack of time and continuity in monitoring (4 out of 29), insufficient expertise (4 out of 29) and technology/equipment (4 out of 29), and gaps in the management and administrative framework (4 out of 29), such as the absence of comprehensive management plans. Some respondents also noted that the size of the monitoring area posed significant challenges (3 out of 29), and better collaboration and knowledge sharing among managers could improve the monitoring strategy (4 out of 29), mirroring patterns found with eDNA methods specifically.

Regarding the gaps and limitations of the MPA network itself, many respondents highlighted the need for improved collaboration (14 out of 29). They suggested that conducting twinning programs and organizing more regular meetings and cooperation forums to exchange expertise and best practices, as well as to share data, would significantly enhance the network. Other frequently mentioned limitations include management and administrative issues (7 out of 29), such as the lack of binding guidelines and targets and inadequate coordination by national and supranational institutions. Funding constraints and the diversity and lack of inclusiveness within the network were also noted (respectively by 6 and 4 out of 29). Respondents emphasized that it is not always possible to apply the same models across different regions or countries, and not all member states have the same level of environmental awareness and management capacity, which affects the quality of MPA management and monitoring.

Discussion

The analysis of the MedPAN network reveals a diverse and multi-level governance landscape of MPA governance, with significant representation from national government administrations. The dominance of local-level operations suggests a strong focus on addressing specific, localized environmental and conservation issues.

The mixed results regarding the implementation of management plans reflect varying levels of management effectiveness across the network. The fact that some of the respondents reported no management plans or unimplemented plans highlights areas where MPAs are potentially vulnerable due to inadequate governance frameworks, as already underlined by the European Commission [7]. This issue is particularly pronounced in Croatia and Greece, where the lack of management plans is more prevalent.

Conversely, the high rate of full implementation in France and partial implementation in Slovenia and Spain suggests successful governance models that could serve as best practices for other regions. The correlation between management plan implementation and the type of MPA designation (national or combined with Natura 2000 sites) suggests that legal frameworks and funding mechanisms associated with national designations may provide better support for effective management.

The widespread practice of monitoring within MPAs is encouraging, yet the significant proportion of ad hoc monitoring points to a need for more structured and systematic approaches [8]. The presence of well-implemented monitoring and evaluation systems in some MPAs indicates that effective frameworks do exist and can be adopted more widely. The absence of adaptive management based on monitoring in Greece and Slovenia is a critical gap that needs to be addressed to enhance the effectiveness of conservation efforts in these countries.

The prevalent use of visual census as a monitoring tool aligns with traditional methods, but the emerging use of eDNA metabarcoding is noteworthy. The positive perception of eDNA metabarcoding by its users highlights its potential as a valuable tool for biodiversity monitoring [9]. The reported efficiency of eDNA methods, despite acknowledged areas for improvement, suggests that expanding its use could enhance monitoring capabilities across the network. Furthermore, the better performance reported by respondents using eDNA approaches indicates that integrating innovative technologies can potentially lead to more effective MPA management.

Notably eDNA metabarcoding offers several advantages over traditional monitoring methods such as its ability to detect a broader range of species, including those that are elusive or present at low densities [4]. This capability is particularly valuable for monitoring biodiversity in MPAs where e.g. understanding protected and invasive species presence is critical for effective management. Additionally, eDNA methods are less invasive and can provide quicker results, making them suitable for large-scale and frequent monitoring efforts [10].

The positive feedback from managers using eDNA methods further underscores its utility in providing reliable data for adaptive management. These managers reported better implementation of management plans and more effective monitoring systems, highlighting eDNA's potential role in enhancing the overall management framework of MPAs. As such, promoting the use of eDNA metabarcoding across the MedPAN network could address several current limitations and improve the robustness of MPA monitoring and management. Moreover, those MPAs managers who did not use eDNA also reported a significantly lower level of data-sharing and cooperation among MPAs managers within the MedPAN network, suggesting a possible gap between the two groups. The MedPAN network, through enhanced and fostered cooperation and data sharing, could provide the opportunity to fill this gap and eventually help to facilitate a better uptake of eDNA approaches and data sharing for biodiversity monitoring. Enhancing data-sharing protocols and fostering regular communication and cooperation forums could significantly improve the effectiveness of MPA management by facilitating the exchange of knowledge and best practices.

Recommendations

To address the identified gaps and limitations, several key recommendations can be made:

i. Enhance Funding and Resources: Increasing financial support and investing in capacity-building initiatives are crucial to overcoming the primary constraints of funding and human resources. This could involve seeking additional funding from international organizations, government budgets, and private sector partnerships.
ii. Standardize Monitoring and Data-Sharing Practices: Developing standardized protocols for monitoring and data-sharing can enhance comparability and collaboration across the network. This could include the adoption of eDNA metabarcoding as a complementary monitoring tool and the establishment of centralized data repositories accessible to all MPA managers.
iii. Strengthen Regional Cooperation: Promoting regular meetings, workshops, and twinning programs can facilitate the exchange of expertise and best practices. Establishing regional cooperation frameworks can also help address transboundary ecological challenges and improve overall network coherence. The results suggested some difference in performance between countries, that could benefit from a systematised network to share expertise and know-how.
iv. Promote Adaptive Management: Encouraging the adoption of adaptive management practices based on robust monitoring and evaluation systems can enhance the responsiveness and effectiveness of MPA management. This involves regularly reviewing and adjusting management strategies based on monitoring results and emerging scientific knowledge.

Conclusion

The management and monitoring of Marine Protected Areas (MPAs) within the MedPAN network exhibit both strengths and areas needing improvement. The diverse governance structures and varying levels of management plan implementation highlight the complexity and challenges faced by MPA managers across the Mediterranean. While traditional monitoring methods remain prevalent, the integration of eDNA metabarcoding presents a significant opportunity to enhance biodiversity monitoring and adaptive management practices.

eDNA metabarcoding has demonstrated considerable potential in providing comprehensive, efficient, and non-invasive monitoring solutions. Its ability to detect a wide range of species, including those difficult to observe through traditional methods, makes it a valuable tool for improving the accuracy and scope of biodiversity assessments. The positive outcomes reported by managers utilizing eDNA methods underscore its effectiveness and the necessity for broader adoption across the network.

To address the identified gaps and limitations, the following key actions are recommended: enhancing funding and resources, standardizing monitoring and data-sharing practices, strengthening regional cooperation, developing comprehensive management guidelines, and promoting adaptive management based on robust monitoring data. By implementing these strategies, the MedPAN network can significantly improve its management and monitoring frameworks, ensuring the sustainability and ecological health of Mediterranean MPAs.

In conclusion, the adoption of innovative technologies like eDNA metabarcoding, coupled with strategic improvements in governance and resource allocation, holds the promise of transforming MPA management in the Mediterranean. This holistic approach will enable more effective conservation efforts, better protection of marine biodiversity, and greater resilience of marine ecosystems in the face of ongoing environmental challenges.

Supplementary material

The questionnaire can be found on Figshare doi: 10.6084/m9.figshare.27060172

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MONITORING PHENOLOGICAL TRAITS OF A COASTAL MEDITERRANEAN MAQUIS AREA THROUGH AUTOMATED SYSTEMS

Carla Cesaraccio, Alessandra Piga, Andrea Ventura, Angelo Arca, Pierpaolo Duce

Abstract: Understanding ecosystem dynamics in an era of global change and declining biodiversity requires monitoring biotic components such as plant behaviors and traits. Innovative integrated systems using high-frequency digital images automate vegetation tracking and record of detailed morphological and phenological data. In this study, a description of prototypal monitoring systems based on repeated digital images for detecting changes in phenological traits of Mediterranean coastal maquis in North-West Sardinia is reported. Developed at CNR Laboratories, the systems use high-resolution cameras on automated robots to perform (1) image acquisition, (2) transmission, and (3) post-processing phase. High-resolution images were analyzed to extract Vegetation indices (ExG, REI) from RGB chromatic coordinates. Vegetation Indices patterns were related with phenological traits. Main results highlighted how these systems can be a valid support for monitoring phenological behaviors of vegetation, even in a rugged environment such as Mediterranean coastal ecosystems. This study advances knowledge of plant responses to environmental changes supporting ecological and environmental studies.

Keywords: Near Surface Monitoring System, Phenological Traits, High-Resolution Digital Images, Vegetation Indices.

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Carla Cesaraccio, Alessandra Piga, Andrea Ventura, Angelo Arca, Pierpaolo Duce, *Monitoring phenological traits of a coastal mediterranean maquis area through automated systems*, pp. 144-155, DOI: 10.36253/979-12-215-0556-6.12

Introduction

Biodiversity faces increasing threats, with about 25 % of species at risk of extinction [8]. Effective ecosystem monitoring requires biotic data, but conventional surveys are highly skilled and labour-intensive and thus making regular, comprehensive biodiversity assessments challenging [1,11].

Low-resolution, short-term monitoring fails to fully capture ecosystem dynamics [3], while high-resolution methods are costly and invasive, which limit the temporal and spatial range of historical observations [30]. To balance detail, coverage, and frequency, complex and integrated monitoring systems that cover larger areas and gather extensive data are necessary [9,32].

Near-surface integrated systems, based on high-frequency digital image acquisition, provide innovative frameworks for automated vegetation monitoring. They have been used as an ecological monitoring tool for vegetation traits related to phenology, biomass and productivity [7,14,29]. Consumer-grade digital cameras offer a quick, affordable way to increase data volume, both spatially and temporally, and capture species- and site-specific responses. They provide high spatial resolution, robust data collection, and are less weather-dependent compared to airborne and satellite remote sensing [2,18,22].

Phenology significantly impacts ecosystem function, prompting efforts to improve vegetation monitoring networks [16]. The development of the phenocam method has been crucial, linking ground-based phenological observations with global-scale, coarse-resolution satellite data [22]. A phenocam is a digital camera that captures time-lapse images of plant canopies to analyse vegetation seasonal rhythms through colour-based image analysis [21]. They are used in phenocam networks that are globally expanding over Europe, North America, and Asia, such as the EUROPHEN network. Similar networks can also be found in Asia and Australia [6]. These systems enable the recording of standardized, detailed data on plant traits across various ecosystems [23].

The quantitative data derived from phenocam imagery are of high quality, provided that appropriate precautions are taken regarding camera model, settings, and field setup. They exhibit minimal noise and a robust seasonal signal across various ecosystems, including those with evergreen vegetation [24,25,27,28]. Therefore, phenocams offer objective, automated phenological data with high temporal and spatial resolution, often in real-time. They also create permanent visual records, documenting site development, changes, and responses to factors like growth, disturbances, extreme events, and species composition shifts [21].

Vegetation indices extracted by RBG signals can be considered proxies of vegetation properties as they can be defined as spectral data algorithms used for quantitative and qualitative evaluations of vegetation biophysical and biochemical properties, such as growth dynamics, phenology, and abiotic/biotic stress [31].

Images acquired throughout the day over target vegetation are used for creating time-lapse sequences from sunrise to sunset. Essentially, digital images consist of three "layers", each corresponding to one of the three colour channels. The colour and brightness of a given pixel are determined by the intensity in each colour layer, stored as a digital number (DN) triplet [21]. From DNs, data on vegetation colour, such as "canopy greenness," is extracted to assess phenological changes. Specific transition dates, like the onset of spring green-up, can be identified from the seasonal trend of canopy greenness [28]. Green chromatic coordinate (Gcc) measures green intensity relative to total RGB intensity, serving as an index of "greenness", reflecting changes in foliage development and senescence [21].

Various techniques for processing digital images of plant canopies are detailed in the literature. Researchers have addressed data quality and filtering to reduce noise in green trends [14], extraction of phenological dates using curve fitting and smoothing [6], and the use of digital signals as proxies for spectral data related to pigment dynamics [2]. Studies also link leaf measures to plant functions, enhancing understanding of greenness in different biomes [13].

The success of automated cameras systems to capture digital images across time as a means to monitor plant changes, in particular phenology, is mainly due to the low cost, high accuracy, and data record capabilities. Camera systems technique has many advantages over the traditional observation-based monitoring, including: (1) tracking vegetation changes over time through continuous and regular monitoring; (2) phenological observation data systematically recorded and permanently stored; (3) reduced labour and costs of field observations; (4) standardized measurement protocol across sites and reduction of bias due to observer variation in identifying the date of phenological stages, which is typical of traditional monitoring; (5) possible quantitative digital post-processing analyses of phenological patterns. Therefore, to track vegetation changes over long periods, the development of more reasonably priced near-surface proximal sensing systems and the application of easier-to-use, open-source software tools for the analysis of large-scale datasets represent potential solutions to monitoring challenges [11].

In this study, a description of prototypal monitoring systems, based on repeated gigapixel panoramic acquisition, for detecting changes in phenological traits of vegetation, is reported. These systems employ near-surface proximal sensing techniques to achieve higher temporal resolution and better spatial coverage than ground-based observations. The performance of two different prototype configurations were tested over mediterranean coastal ecosystems dominated by evergreen and semi-deciduous shrubland. Some main outcomes from experimental campaigns are also presented to show the potential in describing the phenological pattern of different species.

Materials and Methods

Study sites

The monitoring systems were tested over Mediterranean ecosystems. The experimental sites are located in northwestern Sardinia, Italy, within the Porto Conte - Capo Caccia Natural Reserve along coastal areas (40° 37' N, 8° 10' E, 74 m a.s.l.). The main soil type is Terra Rossa (Lithic Xerorthent and Typic Rhodoxeralfs - USDA 1993. Average annual precipitation amount is of 566 mm. The average annual temperature is 16.4 °C.

Four distinct types of vegetation grow in this area: the Mediterranean maquis, the Quercus ilex forest, the recent pine forest and the garrigue and dominated by bushes and tiny herbaceous plants [5]. The Mediterranean maquis includes both semi-deciduous and evergreen shrub species mainly *Juniperus Phoenicia* L., *Pistacia lentiscus* L., *Phyllirea angustifolia* L., and *Cistus monspeliensis* L. [20].

Monitoring Phenological Automated Systems

The monitoring prototype developed at CNR Laboratories used high-resolution cameras on automated robots with power supply devices. Designed as an evolution of common phenocams, the system focused on image acquisition, local and remote storage, and post-processing and data analysis.

The monitoring systems, mounted on trellis, cover large areas using cameras with robotic systems that enable the Pan-Tilt-Zoom (PTZ) technique, allowing movement across multiple pre-set views.

Image acquisition protocol

To determine the camera setting and the optimal visual coverage (angle of view, depth of field and resolution of the image) of the experimental site, a custom software was developed and field tests were conducted. Series of images of the study area, framed from different angles and positioning the camera lens on a 3-meter height platform, were evaluated.

Two different setting were chosen for each monitoring system. The first, named APOS, was set to acquire one panorama of 36 shots x panorama (3 rows x 12 columns) with a 30 % of image overlapping. The second, named PHATOS, was programmed to capture 44 images, with a horizontal viewing angle of 170°, a vertical angle of 25°, with a 20 % overlap. To minimize the shadow influence due to the trellis, the systems were programmed to acquire daily data at noon.

Image managing and processing

An application routine for semi-automated image management with a Graphical User Interface (GUI), named Vegetation Index Calculator Interface (VINCI), was developed. This modular routine performs the following automated functions: (1) converting files from raw to hr-jpg format with normalized lighting and sharpness, (2) renaming converted files, and (3) organizing files by frame folders. High-resolution panoramas were created daily using advanced stitching algorithms (AutopanoGiga and Roundshot VR Driving software). A semi-automated MATLAB routine (ANNOT_GUI), with a Graphical User Interface, was developed for calculating RGB Chromatic Coordinates and Vegetation Indices (VIs) [7]. Seasonal trends of VIs for species and growing seasons were analyzed to detect phenological traits and vegetation status, highlighting main phenological transition dates.

Results

Monitoring System Architecture: hardware and camera setup

The installation and configuration of system components inside a previously selected experimental area was carried out through the following steps: a) equipment setup in the field; b) deployment of the power supply system; c) sensor positioning; d) data collection and transmission testing.

We refer to the first configuration as APOS (Automated Phenological Observation System), and to the second one as PHATOS (Phenological Automated Tower Observation System) which is an evolution of the first one. The general architecture of APOS and PHATOS includes several components, designed specifically to perform major functions: 1) Image acquisition, made through the use of a camera connected to a robot, so as to frame and pan an area in accordance with the visual coverage of the site of study; 2) Image transmission, permitted by a modem-router for broadband access to the Internet; 3) Image processing: image stitching and elaboration made by remote computer. Following a description of main hardware for each of the system is separately reported.

APOS - Automated Phenological Observation System: the image acquisition is made using a Canon EOS 7D digital camera (18 MPx) with 18-135 mm zoom lens. The acquired images are transmitted from the camera using a specific accessory (wireless file transmitter, WFT) directly connected to the camera body by its proprietary interface. The transmitter allows performing a high-speed wireless file transfer process. WFT Server mode allows a web browser to manually view images stored on the memory card as well as control the camera from a web browser. WFT can connect a hard disk drive for local image storage in addition to a camera memory card. The GigaPan hardware/software system was implemented in APOS (fig.1). For taking numerous photos by panning/tilting the robotic camera mount GigaPan EPIC was used. The acquired images, once transmitted to the remote computer server, are stitched by software (Autopano Giga) to obtain a high-resolution panorama (fig.2).

Figure 1 – Different view of APOS installed in the experimental site Capo Caccia, Italy: system mounted on the trellis with camera/robot inside the protection case (left), camera coupled to GigaPan robot (centre) and power supply system (right).

Figure 2 – One day high-resolution panorama obtained by stitching technics from 36 combined images shooted by APOS in the Capo Caccia experimental site, Italy.

PHATOS - PHenological Automated Tower Observation System: PHATOS is an evolution of the APOS system (fig.3). The design scheme was improved including (1) a pan-and-tilt-head with high-performance robotic arm to capture 360-degree panoramas, (2) a very high-resolution camera (36 Mpx), (3) a protection structure equipped with automatic opening and closing control system integrated with a remote management software system. The images were acquired by using a Nikon D800 camera with AF-S VR Zoom-Nikkor 70-300 mm f/4.5-5.6G IF-ED lens. This camera is directly connected to the Robotic panoramic shooting support Clauss Rodeon VR Head CL. The RODEON modular is an automatic pan-and-tilt-head for segmented panoramic photography, wide-angle shots, 360° and multirow sphere panoramic photography (fig.4). The pan-and-tilt-head can work with horizontal or vertical drive, and comes with a transceiver module, battery adapter, and a camera bar with quick release plate.

Figure 3 – Different view of PHATOS installed in the experimental site Capo Caccia, Italy: system mounted on the trellis with camera/robot inside the protection case (left), camera coupled to Rodeon robotic arm (centre) and power supply system (right).

Sharpness and resolution levels have been set to recognize morphological elements needed to detect phenology at individual level. To obtain a good stitching result from the pictures, the use of a fixed focus has proven to give the best results, along with the use of the same focal length and the same aperture for all the shooting. The system is connected to a Getac S400 semi-rugged notebook which functions as a command centre for the execution of a routine of actions that are repeated on a daily basis. This routine is controlled by the Rodeon Preview 2.4 PRO software, which was set up to automatically starts, controls acquisition parameters, stores parameters, stores raw images on the hard disk, and allows remote control via a remote server. The power system with photovoltaic system is composed of four panels, four batteries, charge regulator, inverter.

A protective structure was added to protect the hardware systems against the negative effects of marine aerosol, and to prevent atmospheric water vapor from condensing on the surfaces. The structure is equipped with a marine plywood box covered with spaced protection panels, to reduce solar radiation and heat conduction of the external surface. All surfaces are covered with white surfaces to reduce the absorption of radiant energy. The box, fixed to a stainless-steel structure and two telescopic guides, is lifted by 45 cm using two electromechanical actuators, that allow opening only during image acquisition each day, operated by a programmable logic control (PLC) system.

Figure 4 – One day high-resolution panorama obtained by stitching technics from 44 combined images shooted by PHATOS in the experimental site Capo Caccia, Italy.

Vegetation indices and phenophase transition dates

Digital numbers (DNs), representing RGB colour channel information, are transformed into chromatic coordinates through ANNOT_GUI. The graphic interface consists of two main sections: (1) File "List", used for the selection of image files; (2) "Image", for the definition of the Region of Interest (ROI), by clicking on the image and draw a polygonal perimeter. ROI is drawn for including as much of the vegetation as possible. As a result, the ROI varied depending on the vegetation available in the field of view that was different for each system with irregular shape and variable size. The GUI is optimized to handle sequences of images representing temporal change of panoramas or single shoot. The output CSV file will include a header containing coordinates of the vertices of the polygon that defines the selected ROI, and results for each processed image. The CSV file can be easily imported into other applications, such as R and Microsoft Excel, for further processing.

Vegetation index patterns during growing seasons are analysed to identify changes in vegetation status through green/red signal variations. Inflection points indicate significant changes, with the Excess Green Index (ExG) highlighting the green-up phenological phase. In fig.5, an example of pattern retrieved from colour signal is shown, as mean daily values of the Vegetation Indices (VIs) ExG and REI (Red Excess Index), calculated for *Cistus monspeliensis* L. and *Pistacia lentiscus* L. The pattern of VIs clearly follows the phenological development of species. *Cistus monspeliensis* is a drought semi-deciduous species, characterised by seasonal leaf dimorphism, producing brachyblasts with small leaves at the end of spring–beginning of summer, and dolichoblasts in autumn–winter, with larger and thinner leaves [20]. The peaks in ExG curve show clearly the seasonal leafing events in spring and autumn whereas the higher values of REI are related to drought periods when Cistus loose most of the spring leaves. *Pistacia lentiscus* is a dioecious sclerophyllous evergreen shrub, well-adapted to harsh growing conditions and drought tolerant. The leaves are leathery and bright green and their senescence occur during summer. The globular fruit start ripening in August and colour change with maturity from red to brown [17]. The ExG signal amplitude growth more than 40 % in late spring when leafing flushing occurs. The increased value of REI, starting in late summer, clearly reveal the ripening of the drupes.

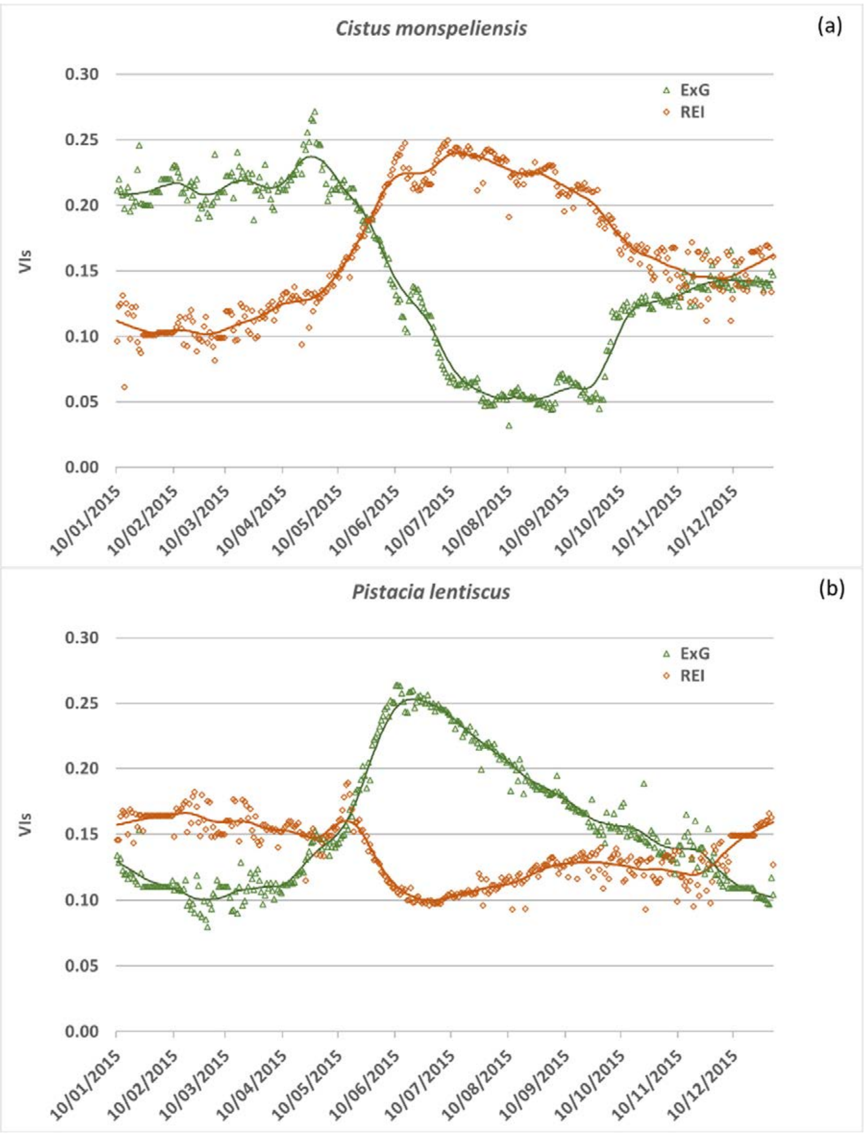

Figure 5 – Mean daily values of the vegetation indices ExG and REI for the semi-deciduous *Cistus monspeliensis* (a) and the evergreen *Pistacia lentiscus* (b) species. Time series Loess smoothing method was applied.

Discussion

Digital cameras can provide objective, automated phenological data with high temporal and spatial resolution, often in real-time. Standard RGB cameras are effective for identifying temporal and spatial patterns in vegetation productivity and composition on different scales [19]. Unlike satellites, these systems can cover the entire growing season with minimal gaps. However, automated, weatherproof systems for capturing time-lapse gigapixel images are rare due to their technical complexity and data management challenges [4]. Such systems, like the GigaPan and Rodeon Clauss Rodeon VR Head CL, implemented in our systems, can stitch overlapping images into high-resolution panoramas, allowing for detailed monitoring of thousands of individual plants across large areas (fig. 2-4). The application of our time-lapse gigapixel image systems gave promising results also for the analysis of a coastal Mediterranean maquis.

Vegetation indices from RGB images such as GCC shows a similar temporal pattern as those from multispectral data (e.g. NDVI). An additional advantage of camera-derived images is that they serve as a permanent visual record of the observed area, providing a unique historical account of site changes over time, including growth, mortality, disturbances, and species composition changes [21,26]. As expected, our system allowed the collection of very high-resolution monitoring datasets, permanently stored, available for additional processing and analysis.

Existing ecosystem monitoring networks lack coordination in the application of sampling protocols and in the choice of camera types and settings [5]. However, significant issues need consideration, such as variations in phenology estimates due to the camera setting (cardinal direction and inclination angle), which affect the estimation of spring budburst [11]. Standardizing sensor direction is essential, but addressing inclination angle impacts is more challenging due to species composition variability. Camera exposure settings, especially during autumn leaf colour changes, also pose challenges [15]. For these reasons, particularly attention was paid to the development of custom software for setting all variables related to camera set-up and field overview parameter acquisition.

RGB-derived indices can vary significantly across different areas, complicating their use for scaling values to larger regions. It remains uncertain if any single color-based index can reliably track seasonal changes in photosynthetic activity across diverse evergreen species and ecosystems [12]. Additionally, mechanistic studies on the physiological basis for seasonal canopy color variations are lacking, adding to uncertainties about the best index to use. In our research several different VIs were calculated and analyzed to verify whether their pattern reveal phenological timing. The phenological traits retrieved by colour VIs are in line with direct phenological observations, confirming the great reliability of the applied methodologies. The proposed approach might represent a real methodological improvement for monitoring ecosystem phenology over natural vegetation.

Conclusions

The use of near-surface proximal sensing methods based on digital images seemed promising for several reasons, including increased data collection rates, standardized datasets permanently stored, and automatic data processing. The implementation of the systems developed in our study have further advantages, including: (1) automation of image management from field acquisition to data processing; (2) advanced calculation of vegetation indices; (3) system interoperability with the most widespread software.

Some main outcomes from this study indicate that the use of digital images seems to be well-suited to identify phenological traits and behaviour in the case of Mediterranean species observed in a coastal area.

Overall, results retrieved from digital images analysis can be a valuable support for ecologists, environmental scientists, and land managers providing information useful to interpret phenological responses of plants to climate change, to improve our understanding on the relationships between phenology and ecosystem processes, and to validate satellite-based data. This approach offers potential to improve data processing but also data modeling, upscaling and extrapolation, opening to further research also in deep learning and cutting-edge machine learning.

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Estimation of gross and net primary production in a coastal forest area undergone to clearcuts

Marta Chiesi, Piero Battista, Lorenzo Bottai, Luca Fibbi, Francesco Manetti, Maurizio Pieri, Bernardo Rapi, Fabio Maselli

Abstract: The current study presents the application of a model combination strategy to analyse gross and net production in a Mediterranean pine wood ecosystem. The test site is in the San Rossore Regional Park (Central Italy), an area originally characterised by the presence of *Pinus pinaster* Ait and *Pinus pinea* L. Since 2004 the former species was attacked by an insect and was therefore subjected to clearcuts around 2012. The latter species, not affected by the insect, has continued to grow, reaching the senescent stage. The evolution of two large stands (i.e., one per species) in terms of gross and net primary production over the years 2013-2022 is then reconstructed by applying satellite-based and process-based models to different datasets: a daily meteorological one, a set of 16-day MODIS NDVI images at 250 m spatial resolution, a LiDAR image taken in 2015 and digital orthophotos referred to 2021. The study shows how this modelling strategy can be successfully used to analyse the influence of climate and management on this forest ecosystem, and to reconstruct the evolution of stands in different growing phase. Such assessment is relevant to provide the information required for sustainable forest management, concerning in particular carbon cycle ecosystem services.

Keywords: Mediterranean pines, development stage, *Matsucoccus feytaudi*, GPP, NPP.

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Marta Chiesi, Piero Battista, Lorenzo Bottai, Luca Fibbi, Francesco Manetti, Maurizio Pieri, Bernardo Rapi, Fabio Maselli, *Estimation of gross and primary production in a coastal forest area undergone to clearcuts*, pp. 156-167, DOI: 10.36253/979-12-215-0556-6.13

Introduction

Forest ecosystems play a fundamental role in the carbon (C) cycle at both local and global scales; studying and monitoring the main processes of these ecosystems is therefore fundamental [1,2]. This is generally achieved using two complementary tools, i.e., remote sensing and biogeochemical models. The former, in fact, provide synoptic and repetitive views of vegetation features and conditions at different spatial and temporal resolutions; on the other hand, the latter can simulate all main vegetation processes, and specifically forest photosynthesis and respirations. The two techniques are therefore suited to be combined for estimating forest C fluxes, and in particular gross and net primary production (GPP and NPP, respectively) [3].

An example of this approach is provided by the strategy developed and experimented by our research group [4]. This strategy consists in combining the outputs of a radiation use efficiency (RUE) model, Modified C-Fix, with those of a model of ecosystem processes, BIOME-BGC. The former requires remotely sensed NDVI images as a fundamental input, while the latter is driven by ancillary data descriptive of forest conditions. The results of the two models are finally combined taking into account the effects of forest disturbances through the use of the ecosystem equilibrium theory [4]. Owing to this configuration, the modelling strategy can be applied to analyze the response of forest ecosystems to climatic changes but is also suitable to investigate on the impact of human activities (forest thinning, clearcuts, etc.).

The current work illustrates how the modelling strategy can be applied to i) disentangle the contrasting impact of climatic and anthropogenic factors on forest ecosystems productivity and ii) estimate the respective evolutions in terms of GPP and NPP. The research is carried out in a Mediterranean coastal area, the San Rossore Regional Park (Central Italy), where two pine forest ecosystems are in different development phases due to the respective disturbance histories and the application of diversified management practices. Specifically, the impacts exerted during a decade (2013-2022) by these conditions on the evolutions of forest GPP and NPP are analyzed and discussed.

Materials and Methods

Study area

The San Rossore Regional Park is situated in a coastal plain close to Pisa (43.73° Lat. N, 10.28° Long. S; Figure 1). This area has been the subject of several investigations concerning all main forest processes, and particularly water and C fluxes, because it included a maritime pine (*Pinus pinaster* Ait.) forest where an eddy covariance flux tower was set at the end of 90es. This forest was then affected by the parasitic attack of an insect (*Matsucoccus feytaudi*) which damaged most pine trees, and was faced by extensive clearcuts carried out during 2009-2012 [5]. Since then, the forest is regrowing as a secondary ecological succession and most pine wood is now dense, with a mean height around 3÷5 m.

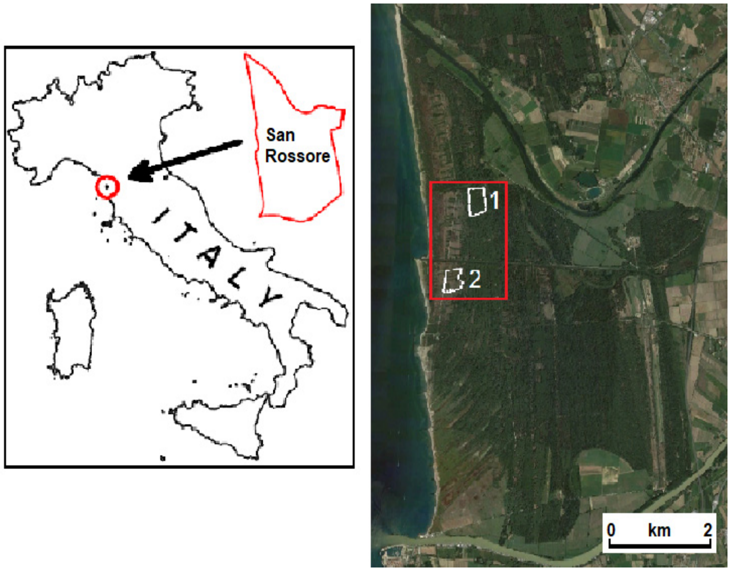

Figure 1 – Geographical position of the San Rossore Park in Italy (left) and 2021 Google Earth image of the park with the location of the selected pine forest stands (right). Stand 1 and 2 are dominated by umbrella pine and maritime pine, respectively.

An adjacent area of the Park, inner to the maritime pine stripe, is dominated by an umbrella pine (*Pinus pinea* L.) forest, which is not vulnerable to the *Matsucoccus* attack. Most of the stands covered by this species were planted more than 80-90 years ago, are now relatively dense and have a mean height of 20÷22 m [6].

The Park therefore includes two pine forest ecosystems which are subjected to the same climate but are in different development phases. This offers the opportunity to investigate on the impact of climatic and anthropogenic factors on forest gross and net primary production. The current study, in particular, focuses on two of the largest forest stands in the Park, the first covered by mature umbrella pines and the second covered by maritime pines which are rapidly regrowing after the clearcuts of 2009-2012 (Figures 1 and 2).

Study data

Daily meteorological data (i.e., minimum and maximum air temperature, precipitation and solar radiation) for ten years (2013-2022) were obtained applying the DAYMET and ERAD algorithms to the ground observations of the LaMMA Consortium [7,8].

NDVI images taken by the Moderate Resolution Imaging Spectroradiometer (MODIS) Terra/Aqua satellite sensor were downloaded from the NASA archive (https://modis.gsfc.nasa.gov). This archive contains pre-processed maximum value composite (MVC) images computed over 16-day periods, at a 250 m spatial resolution; those covering Tuscany over the same years as above (2013-2022) were further pre-processed in order to reduce residual atmospheric contaminations.

A high spatial resolution LiDAR acquisition taken over the Park by a low altitude aircraft flight in May 2015 was also utilized. The products available were 1-m spatial resolution Digital Surface and Digital Terrain Models (DSM and DTM, respectively), which were processed to obtain the Canopy Height Model (CHM) of the study area.

A digital orthophoto of the area was also available for 2021 (Figure 3). More specifically, frames from the August 2021 AGEA flight (flight altitude 2050 m, spatial resolution 0.15 m) were processed to obtain the DSM of the area; these data were processed by means of the Agisoft Metashape Professional software (Version 1.8.3). The main processing steps were the following:

- Georeferencing of the frames using the coordinates, the height of the photo-taking centers and the camera's flight attitude correction data (omega phi and kappa).
- Use of 12 Ground Control Points of known coordinates and elevation to improve the accuracy of the DSM regarding the height of the plants in the study area.
- Creation of 3D models by means of sequential processing steps, such as image alignment, creation of a dense point cloud and creation of 3D surfaces (tiled model).
- Building of the DSM from the dense cloud.
- Building of the DSM-based ortho-mosaic.

a b

Figure 2 – Photos of stand 1 (a) and stand 2 (b) taken in September 2023; the two stands are covered by umbrella pines and maritime pines, respectively.

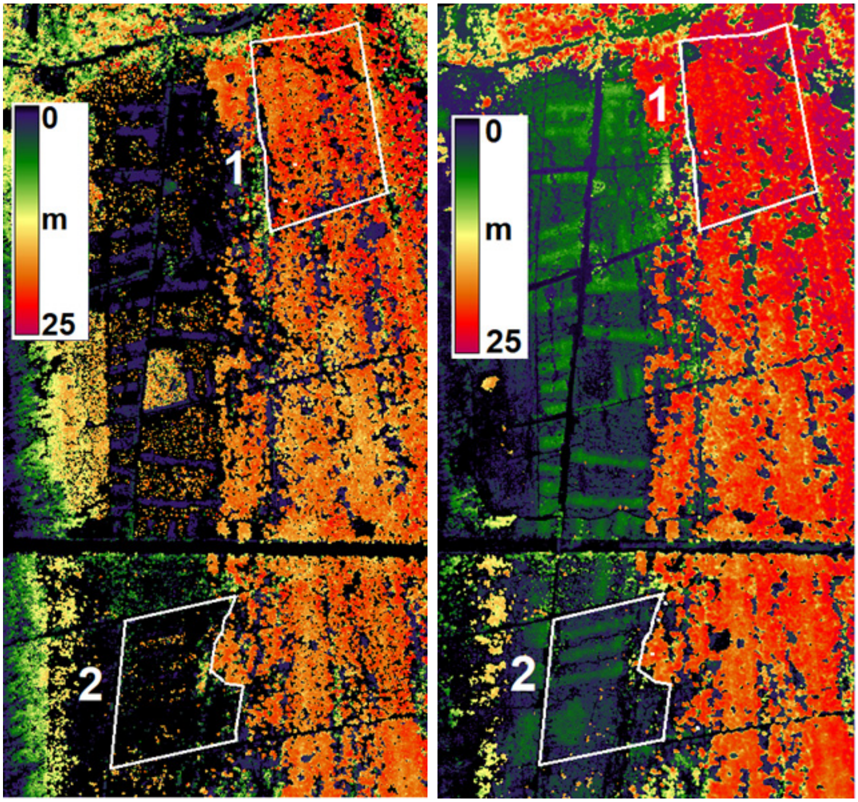

Figure 3 – CHM obtained from the ALS data of 2015 (a) and the orthophoto of 2021 (b) with superimposed boundaries of the umbrella pine (1) and the maritime pine (2) stands.

Modelling strategy

The main characteristics of the models applied (i.e., the satellite-based C-Fix and the process-based BIOME-BGC) and the combination of their outputs are summarized in the following paragraphs.

Modified C-Fix is a RUE model based on remotely sensed data that was proposed by [9] to improve the performance of the original version in water-limited environments. The new model version, in fact, in addition to air temperature, solar radiation and fAPAR, includes a water stress factor (Cws), that is computed by means of standard meteorological data and limits photosynthesis in cases of short-term water stress. Modified C-Fix, therefore, predicts the forest GPP of day i (GPP_i) as:

$$GPP_i = \varepsilon \cdot Tcor_i \cdot Cws_i \cdot fAPAR_i \cdot PAR_i \quad (1)$$

where ε is the maximum radiation use efficiency (1.2 g C MJ^{-1} APAR); $Tcor_i$ is the MODIS temperature correction factor of the forest type following [10]; Cws_i is the water stress factor; $fAPAR_i$ is the fraction of absorbed PAR (derivable from remotely sensed vegetation indices) and PAR_i is the solar incident PAR. The water stress scalar of day i (Cws_i) is computed as:

$$Cws_i = 0.5 + 0.5\ AW_i \qquad 2$$

where AW_i is the ratio, bounded to 1, between rainfall and potential evapotranspiration, both cumulated over the preceding two months.

BIOME-BGC is a bio-geochemical model that simulates the storage and fluxes of water, C and nitrogen within the major terrestrial ecosystems [11]. It requires as input daily meteorological data, general environmental information (i.e., soil, vegetation and site conditions) and parameters describing the ecophysiological characteristics of the local vegetation. The model simulates photosynthesis, respiration and allocation processes corresponding to the requested study years, after having simulated the ecosystem quasi-equilibrium condition based on local eco-climatic features. The currently used model version (i.e., 4.2) includes parameter settings for seven main biome types that were modified to adapt to water-stress conditions.

C-Fix has the advantage of providing a direct remote sensing-based assessment of total forest GPP, while BIOME-BGC allows a complete simulation of all main ecosystem processes. This implies that BIOME-BGC functioning can be improved by multiplying its estimates for the ratio between C-Fix and BIOME-BGC GPP [4]. The same estimates can be corrected to account for the difference between actual and potential forest conditions, being the former mostly determined by natural and/or human-induced disturbances. Therefore, the ratio between the actual (measured or estimated) and potential (simulated by BIOME-BGC) growing stock volume (GSV) is taken as an indicator of the distance from ecosystem equilibrium and used to correct the photosynthesis and respiration estimates obtained by the model simulations. The actual forest NPP of day i (NPP_i) is consequently estimated as [12]:

$$NPP_i = GPP_i \cdot FC - Rgr_i \cdot FC - Rmn_i \cdot NV \qquad 3$$

where GPP_i, Rgr_i and Rmn_i represent the BIOME-BGC estimates of photosynthesis, growth and maintenance respirations, respectively, all improved by the combination with C-Fix GPP; the terms FC (forest cover) and NV (normalized volume) describe the ecosystem distance from the quasi-climax condition [4]. More specifically, NV is the mentioned ratio between actual and potential GSV and FC represents the fractional tree canopy cover obtained by combining NV and the potential tree leaf area index following Beer's law [4].

Data Processing

The data processing consisted of applying the combined modelling strategy to the two aforementioned forest stands: the first is an old-growth stand of about 15 ha dominated by umbrella pines, while the second is a stand of nearly 20 ha originally covered by the maritime pine, clearcut after the insect attack in 2012 and now occupied by a secondary succession (see also Figures 1-3).

The 2013-2022 daily meteorological data derived from the LaMMA database were combined with the NDVI values extracted from four MODIS pixels approximately coincident with the two stands. These data were used to drive Modified C-Fix (Equation 1), while a BIOME-BGC version parameterized for Mediterranean pines (both umbrella and maritime pines are included in this biome type) was applied using the ground datasets. Three series of GPP estimates were thus obtained, one yielded from the bio-geochemical model referred to both stands, the other two yielded from Modified C-Fix driven by the NDVI of the two stands (i.e., NDVI 1 for umbrella pine and NDVI 2 for maritime pine).

The application of BIOME-BGC also yielded NPP estimates descriptive of quasi-equilibrium condition. The actual status of the two stands was instead accounted for by the model combination strategy, i.e. through the application of Equation 3. The scalars required by this equation (NV and FC) were obtained from the analysis of the 2015 LiDAR dataset using the allometric relationships described in [13]. The two scalars were then annually updated by increasing the GSV values with the woody increments obtained from the conversion of the respective NPP estimates [14]. These model applications therefore yielded an additional series of annual NPP and GSV estimates for the two selected stands.

The evaluation of the modelling approach was performed by checking the reproduction of the NV values at 2021, year for which independent GSV observations were yielded by the analysis of the available orthophotos. The dependence of the estimated NPP series on the respective model drivers (i.e., the meteorological water stress factor and the NDVI) was finally evaluated by standard correlation analyses.

Results

Figure 4 shows the evolution of the meteorological water stress scalar (i.e. AW, as defined in Equation 2) in the study area during the examined 10-year period (2013-2022). A clear AW decrease is observed ($y = -0.018 x + 0.748$, $r^2 = 0.614$). This evolution is mostly due to a quite regular increase in mean air temperature, which induces a corresponding increase in land water demand, i.e., potential evapotranspiration (data not shown).

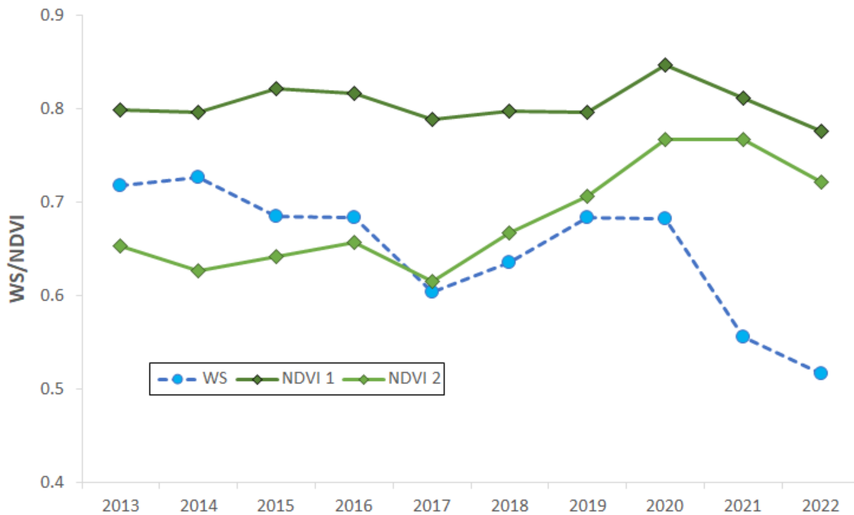

Figure 4 – Evolutions of WS (equalized to the AW scalar) and NDVI in the examined forest stands during the 2013-2022 period; NDVI 1 and NDVI 2 refer to stand 1 and stand 2, covered by umbrella pines and maritime pines, respectively.

The same figure shows the mean NDVI evolution of the umbrella pine (NDVI 1) and maritime pine (NDVI 2) stands. The former shows a nearly stable, high NDVI (i.e., equal to or higher than 0.8), which is dependent on the AW scalar (Table 1). This indicates that this forest stand maintains a nearly stable canopy cover, which is confirmed by the joint analysis of the two CHMs derived from the 2015 ALS data and the 2021 orthophotos (Figure 3a-b); in both cases, the pine tree canopy cover is over 0.8.

The maritime pine stand instead shows a NDVI increase in opposition to AW, i.e. from around 0.65 to about 0.8. This reveals the tendency to re-grow of the stand, typical of the secondary succession after the clearcuts of 2009-2012. Once again, the 2015 and 2021 CHMs corroborate this observation; in fact, while in the former almost no trees are detected, the latter reveals the presence of trees grown up to 6-8 m (see also Figures 2 and 3). This NDVI pattern is confirmed by the correlations of Table 1, particularly concerning the opposite trends of NDVI 2 and AW.

The use of these NDVI series to initialize the C-Fix model provides the GPP values shown in Figures 5 and 6. In the case of the umbrella pine stand, the simulated GPP is around 1900-2000 g C m^{-2} year^{-1} and follows a slight decreasing trend (Figure 5), similar to that observed for AW. The same figure shows the evolution of NPP reconstructed after combining the outputs of two models and using the 2015 NV derived from the ALS data. The estimated NPP varies around 560 g C m^{-2} year^{-1}, with a minimum of 370 g C m^{-2} year^{-1} in 2017 and a maximum of 733 g C m^{-2} year^{-1} in 2020. The simulated NPP series is significantly dependent on both AW and NDVI (Table 1). The scalars of equation 3 used to initialize the simulation are descriptive of a mature forest (i.e., NV = 0.60 and FC = 0.72). This implies limited relative NV and FC increases simulated for the study period, which range from 0.58 to 0.64 and from 0.71 to 0.75, respectively. The correctness of this simulation is confirmed by the NV value estimated for 2021, that is very close to the observation (0.630 and 0.628 respectively).

Figure 6 shows the maritime pine evolutions of GPP, NPP and NV simulated as above. In the current case, the GPP increases from about 1380 to 1500 g C m^{-2} $year^{-1}$ reflecting the already observed NDVI 2 increase in opposition to WS variation (see also Figure 4 and Table 1). The simulated NPP follows an increasing trend that is similar to that of NDVI, showing a highly significant correlation with this (Table 1). The NPP of this stand rises from about 500 to 1000 g C m^{-2} $year^{-1}$, concurrently with the NV scalar which increases from about 0.04 to 0.11, while FC rises from around 0.43 to 0.80. All these patterns are confirmed by the good correspondence between the NV values observed and simulated for the year 2021, which are both around 0.10.

Table 1 – Correlation between the major drivers and the simulated NPP at the selected pine forest stands (* = significant correlation, P<0.05; ** = highly significant correlation, P<0.01).

	NDVI 1	NDVI 2	NPP 1	NPP 2
AW	0.410*	-0.426*	0.773**	-0.547*
NDVI 1		0.364	0.645**	0.242
NDVI 2			0.197	0.931**
NPP 1				0.051

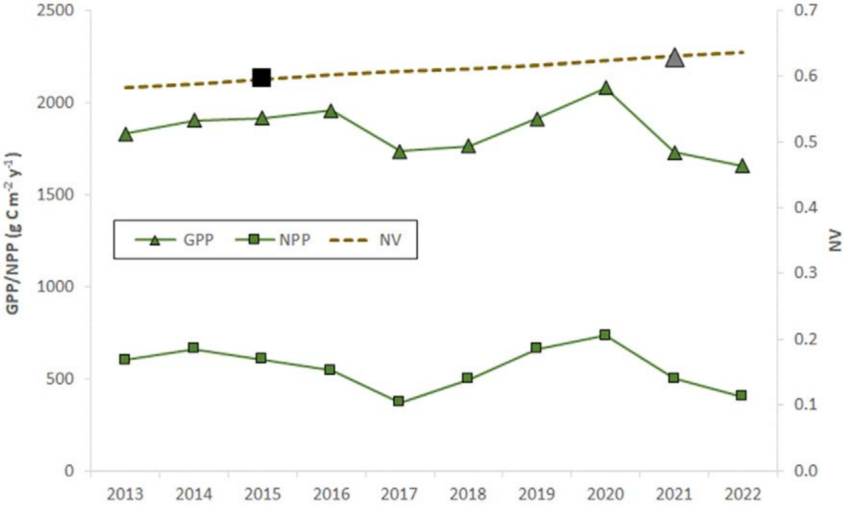

Figure 5 – Annual evolution of the GPP, NPP and NV of the umbrella pine stand during the 2013-2022 period; the black square and the grey triangle represent the NV values obtained from the ALS data of 2015 and the orthophotos of 2021, respectively.

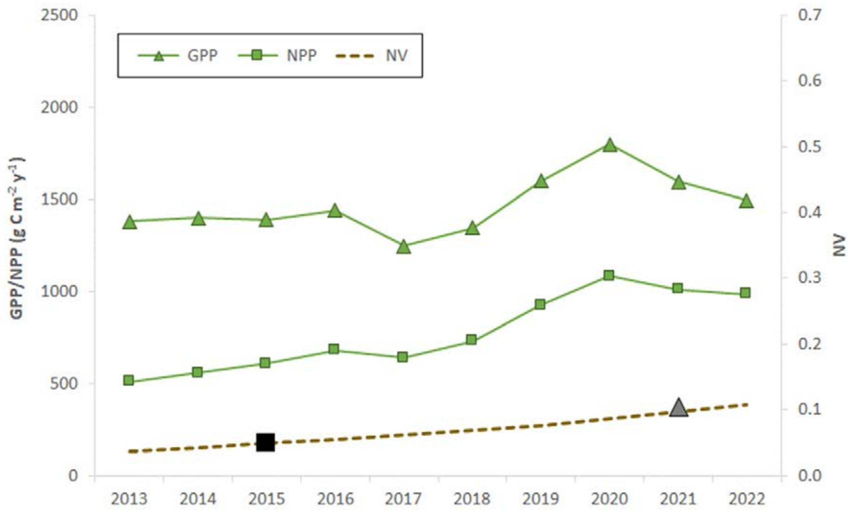

Figure 6 – Annual evolution of the GPP, NPP and NV of the maritime pine stand during the 2013-2022 period; the black square and the grey triangle represent the NV values obtained from the ALS data of 2015 and the orthophotos of 2021, respectively.

Discussion and Conclusion

The current study is based on the capability of Modified C-Fix to predict forest GPP in Mediterranean areas, which has been demonstrated in previous investigations [9]. A similar efficiency has been proved for the calibrated BIOME-BGC version to simulate all forest processes in the same region. The combination of the two model outcomes following the described strategy is then capable of predicting actual forest net C fluxes, i.e., affected not only by local climate and soil but also by anthropogenic disturbances.

Owing to these properties, the strategy can be applied to analyzing the impacts of both natural factors and human-induced disturbances on these fluxes. This has been currently done in a Mediterranean coastal area covered by two pine forest species in different development phases relying on the availability of ancillary and satellite data from various sources.

The results obtained show that the first stand, representative of the mature umbrella pine forest, is mostly controlled by meteorology, i.e., by the increasing dryness of the area, which induces slightly decreasing GPP and NPP trends. On the contrary, the second stand, representative of a secondary succession after clearcuts, counteracts the tendency to increasing dryness by rapid regrowing, which induces an almost constant increase of NDVI and, consequently, GPP. Still in accordance with the mentioned theory, the simulation of NPP is also affected by the progressive increase of the two vegetation scalars (NV and FC), which takes into account the intense biomass accumulation typical of the initial phase of a secondary succession. As a consequence, the NPP predicted for this stand starts from low values and rapidly increases up to relatively high levels. This phenomenon is obviously accompanied by an evident storage of woody biomass, which is testified to by the increasing tree canopy height observable in the field. The mean canopy height of the stand, in fact, rises from nearly 0 m in 2013 to 3-4 m in 2023.

While a complete validation of the GPP and NPP estimates found is not currently feasible, the mean values of these variables are comparable to those measured in similar environments. The average GPP values observed by an eddy covariance tower placed in the same area, in fact, were around 1600-1800 g C m^{-2} $year^{-1}$ [9].

The results currently achieved are affected by several sources of uncertainty. In addition to the limits of the modelling background, the use of different interpolated and remotely sensed input datasets inevitably introduces inaccuracy that cannot be quantified. In particular, a major uncertainty source derives from the different airborne sensors used to yield the CHMs of 2015 and 2021. In general, in fact, CHMs obtained from high spatial resolution ALS data are quite accurate, while this is less the case for CHMs derived from orthophotos [15]. This likely affects the results of the current analysis to a degree which is hardly quantifiable without independent observations collected on the ground.

The current work has therefore provided only a first indication of the potential of the proposed modelling strategy to quantify the different C accumulation capacities of forests subjected to the same meteorological constraints but in diverging development phases. Within this approach, the use of remotely sensed data collected from different sources is fundamental to characterise both the structure and the GPP of the different forest stands.

More generally, the capability to assess gross and net primary production is relevant for providing the information required for sustainable forest management, concerning in particular the ecosystem services linked to the C cycle. The potential of the strategy, however, should be confirmed by future investigations carried out using ground and remote sensing observations of both C fluxes and stocks taken in the same and other forest areas.

Acknowledgements

The authors wish to thank the park administration in the person of F. Logli for providing access to the study area and information on the pine forest stands.

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MAPPING *YUCCA GLORIOSA* IN COASTAL DUNES: EVALUATING THE COST AND TIME EFFICIENCY OF PHOTOINTERPRETATION, MACHINE LEARNING AND FIELD DETECTION APPROACHES

Elena Cini, Flavio Marzialetti, Marco Paterni, Andrea Berton, Alicia Teresa Rosario Acosta, Daniela Ciccarelli

Abstract: Biological invasions threaten biodiversity and cause significant economic and ecological damages. Effective management of invasive species is crucial, as highlighted by the European Community's Regulation 1143/2014 on Invasive Alien Species (IAS). This study focuses on coastal dune ecosystems, particularly assessing the time and cost-effectiveness of three monitoring methods for detecting and mapping alien plants: photointerpretation, machine learning classification, and field monitoring. *Yucca gloriosa* L., an invasive plant in Regional Park of Migliarino-San Rossore-Massaciuccoli (Tuscany, Italy), served as the target species. Using RGB DJI Phantom 4 Pro v. 2.0 and DJI P4 Multispectral drones, images were analyzed via photointerpretation and machine learning. Photointerpretation, though precise, was time-consuming and subjective. Machine learning minimized human effort but required extensive computing. Field monitoring produced accurate maps but was labor-intensive and limited by accessibility issues. This study concludes that UAV-based monitoring of *Y. gloriosa* is optimal for balancing cost and time efficiency in coastal dune ecosystems.

Keywords: alien plants, drones, monitoring, RGB and multispectral, mapping

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Elena Cini, Flavio Marzialetti, Marco Paterni, Andrea Berton, Alicia Teresa Rosario Acosta, Daniela Ciccarelli, *Mapping* Yucca gloriosa *in coastal dunes: evaluating the cost and time efficiency of photointerpretation, machine learning and field detection approaches*, pp. 168-178, DOI: 10.36253/979-12-215-0556-6.14

Introduction

Coastal dunes are dynamic transitional environments characterized by strong sea-to-inland gradients, which profoundly shape the composition of plant communities [1,9]. Serving as primary barriers against the impacts of climate change, encompassing rising sea levels and extreme weather phenomena, coastal ecosystems provide invaluable services such as coastal protection and carbon sequestration [2,29,31]. However, these habitats face substantial global threats due to human-induced activities, notably urbanization, tourism, and coastal erosion [10,14]. According to the 4th European report on habitat conservation, over 85% of coastal habitats are in poor conservation status, with a deteriorating trend [34].

Of considerable concern is the phenomenon of biological invasions, facilitated by human mobility, resulting in the translocation and colonization of species from their native areas to new regions [35]. Invasions by alien plant species often lead to flora homogenization, biodiversity loss driven by competition for space and other resources, as well as changes in biogeochemical cycles [11,21,37]. Beyond biodiversity implications, invasions pose significant economic challenges. A previously estimated 20 billion euros annually are required for monitoring, controlling, and mitigating the impacts of alien species in Europe [18], and to date the costs are almost certainly increased. To address this, the European Community enacted Regulation 1143/2014, providing explicit outlines for the prevention, reduction, and mitigation of alien species impacts on ecosystems. Effective management of alien species includes prevention, early detection and eradication, and control [7]. Prevention is paramount to mitigate the introduction of new species, while early detection and eradication protocols are crucial when preventive measures fail. Conversely, established populations of alien species require ongoing management and control efforts [7,38]. Monitoring plays a vital role in assessing species propagation and devising strategies to safeguard native biodiversity [7].

Field monitoring predominates as the method for tracking alien plant species distribution, often requiring substantial sampling efforts and the involvement of botanical experts. This entails significant temporal and economic investments, compounded by potential inaccessibility in certain areas. Field monitoring is particularly favored in contexts like forest ecosystems, especially for examining canopy-inhabiting species [8,13].

In recent decades, innovative methodologies have emerged for surveilling alien plant species, notably through satellite or drone imagery analysis [28,41]. A multitude of such images are now readily accessible, offering crucial high resolutions for coastal habitat studies [19,27]. Remote Sensing assumes significance for its seamless acquisition of continuous spatial data over time [17,20,39]. Utilizing drone or satellite imagery, for photointerpretation, and semi-automatic or automatic monitoring tools for alien species, allows for reduced time and cost in monitoring activities, expanded study areas, and access to previously inaccessible regions [25].

Along Mediterranean coastal dunes, particularly in Tuscany (Italy), *Yucca gloriosa* L. stands out as one of the most invasive alien plants. Native to the eastern coasts of North America, this species was introduced to Europe primarily for its ornamental qualities, notably its large whitish inflorescence [15,33]. Characterized by a caespitose growth habit and elongated ribbon-like foliage, *Y. gloriosa* faces challenges in sexual reproduction due to the absence of *Yucca* pollinators in European ecosystems. Instead, it relies on rhizome propagation, leading to rapid expansion and the formation of dense monospecific nuclei. Physiologically, *Y. gloriosa* displays an intermediate photosynthetic pathway between C3 and CAM, enhancing its resilience to drought conditions [36]. Moreover, its unique photosynthetic metabolism yields distinct spectral characteristics, which can be exploited for monitoring via multispectral imaging techniques [5]. In Tuscany, *Y. gloriosa* predominantly colonizes fixed dunes alongside *Juniperus* sp. pl., habitats of priority relevance to the European Community, necessitating ongoing monitoring efforts for effective management.

The aim of this work is to compare three methodologies used for monitoring *Y. gloriosa* in coastal dunes within Tuscany: field monitoring, image photointerpretation, and machine learning. The evaluation will focus on their cost and time efficiencies to suggest effective management measures.

Figure 1 – Study area highlighted in red within Bufalina Reserve in the Regional Park of Migliarino - San Rossore - Massaciuccoli from Google Satellite image (2024 Airbus).

Materials and methods

Study area

The study area encompasses a portion of coastal dunes within the Regional Park of Migliarino-San Rossore-Massaciuccoli in northern Tuscany. This park, spanning approximately 230 km^2, features a Mediterranean climate, with an average temperature of 15.2 °C and average annual rainfall of 879 mm recorded between 1991 and 2020 (https://www.lamma.toscana.it/clima-e-energia/climatologia/clima-pisa). Specifically, our focus lies on the coastal area of 3-ha inside the Bufalina Reserve, which spans 4 km of coast between Marina di Vecchiano (Pisa) and Torre del Lago (Lucca), covering a total area of about 30 ha (Fig. 1). The dune ecosystems within our study area represent some of the best preserved in Tuscany, hosting the whole psammophilous series and a variety of endemic species, such as *Centaurea aplolepa* Moretti subsp. *subciliata* (DC.) Arcang and *Solidago virgaurea* L. subsp. *litoralis* (Savi) Briq. & Cavill. However, since the 2000s, the Bufalina Reserve has faced biological invasions by plant species such as *Oenothera* sp. pl., *Amorpha fruticosa* L. and *Yucca gloriosa* L., leading to the initiation of the LIFE project DUNETOSCA (2005-2009) aimed at monitoring and eradicating these invasive species [32].

Remote sensing and field monitoring

To map the distribution of *Y. gloriosa* within the study area using Remote Sensing, we employed Unmanned Aerial Vehicles (UAVs) to collect drone imagery, utilizing two distinct types: the DJI Phantom 4 Pro v. 2.0 for Red-Green-Blue (RGB) images, and the DJI P4 Multispectral for multispectral imagery. The first UAV is equipped with a 20-megapixel RGB camera and a 1-inch CMOS sensor, enabling the capture of high-resolution images (less than 1 cm/px), with a flight autonomy of approximately 30 minutes contingent upon altitude and weather conditions. Conversely, the multispectral UAV features six 2 Mpx sensors, including five for spectral bands (Blue 450 nm ± 16 nm, Green 560 nm ± 16 nm, Red 650 nm ± 16 nm, Red Edge 730 nm ± 16 nm, and Near Infrared 840 nm ± 26 nm) and one for RGB. To standardize multispectral data, calibration panels with specific reflectance values were positioned on the ground. These images obtained with this drone were subjected to a 5 cm/px resampling due to the large amount of data related to multispectral images; furthermore, the DJI P4 Multispectral was employed to capture data for the Digital Surface Model (DSM) using a Structure-from-Motion (SfM) approach. This method accurately depicts the terrain's topography and surface features, including vegetation and structures, by generating a dense point cloud. To acquire UAV images, the open-source software PIX4DCapture (https://www.pix4d.com/it/) was employed. This software facilitates the planning and execution of flights, allowing for the selection of the study area and the overlap between collected images. The UAV flights were performed at 30 m and 35 m respectively for multispectral and RGB images, setting their image overlap to 90 % and 80 %. All flights were conducted between 12:00 a.m. and 2:00 p.m. to minimize the shading effect, which could impact photointerpretation [30]. Subsequently, Agisoft Metashape (https://www.agisoft.com/) was utilized for the image orthorectification phase. This involved generating large orthophotos for both RGB monitoring and all spectral bands. For all the processing phases, an IntelCore i7 computer with 64 GB RAM and 4 TB hard memory was employed.

The RGB orthophotos collected were used for mapping *Y. gloriosa* in the study area through photointerpretation. This method was developed by uploading the orthophotos on the open-source geographic information system QGIS (https://qgis.org/it/site/, versions 3.16 and subsequent). This software allowed an easily manual creation of polygons around the shape of the invaded nuclei; further details are described in [4].

A machine learning approach was developed to monitor *Y. gloriosa*'s distribution in the study area by using DSM, RGB and multispectral images [5]. Vegetation indices, such as Green Normalized Differences Vegetation Index (GNDVI), Normalized Differences Vegetation Index (NDVI) and Optimized Soil Adjusted Vegetation Index (OSAVI) were extracted from multispectral images and were employed for the analysis. Those indices furnish ecological and physiological information about the environment, and all are suggested for monitoring biomass and photosynthetic efficiency. Those three indices are suggested in other studies about alien plant monitoring through images [16,23,24].

Firstly, the RGB orthophoto of 1-ha inside the study area was subjected to image segmentation following a Geographic Object Based Image Analysis approach (GEOBIA), which is recognized as successful in alien plants detecting [3,16,23]. Then for classification, we employed Random Forest algorithm on R (https://www.r-project.org/) by reference photointerpreted classified points to distinguish between invaded and non-invaded areas. The information learnt by the algorithm was used for predicting *Y. gloriosa*'s cover in the remaining 2 ha.

On the other hand, monitoring of alien plants primarily occurs in the field through visual identification and coverage estimation utilizing transects or vegetation plots, such as those employing the Braun-Blanquet cover scale. In our investigation, we merged information gathered from various projects to compare the time and resource expenditure associated with this monitoring methodology. Initially, we sourced data from the LIFE project "DUNETOSCA" report [32] for obtaining information about the costs of creating *Yucca gloriosa* maps across the study area through merging pre- and post-eradication field phytosociological monitoring with aerial image analysis for shapefile generation. Subsequently, information regarding time and costs for field monitoring was obtained from an ongoing project. In this project, three botanical experts deployed 302 random points in the study area to assess the field effort and validate the maps created using photointerpretation and machine learning.

Costs, time, and accuracy assessment

Regarding the cost estimations for monitoring, they have been derived through a comprehensive survey evaluating the pricing quoted by experienced professionals within the pertinent field. On average, the remuneration per hour for an operator is approximately 50 euros. Conversely, the cost projections for field monitoring within the LIFE project DUNETOSCA were estimated at approximately 7500 € for the whole Bufalina Reserve [32], while the expense for identifying field points corresponding to 1 % of the study area was about 750 € for 5 hours. For UAV monitoring, acquiring the licensed application for orthomosaics generation, Agisoft Metashape, costs approximately 200 €.

Regarding the temporal requirements for conducting the monitoring, data has been amassed from flight planning and execution, reports from Agisoft Metashape, and personal field experience pertaining to photointerpretation and the GEOBIA approach. For assessing the accuracy of the photointerpretation and machine learning maps, we involved the 302 random points. Typical accuracy metrics suggested for Remote Sensing were calculated [6,40], such as:

- Overall Accuracy (OA): (TP+TN)/(TP+FN+TN+FP);
- Cohen's Kappa (K): (Po-Pe)/(1-Pe)
- True Skills Statistics: TP/(TP+FN)+TN/(TN+FP)-1
- Balanced Accuracy: 0.5 × TSS + 0.5.

Here, True Positives (TP) and True Negatives (TN) represent the correctly classified points in comparison to field identification. False Positive (FP) are points classified on the map as invaded, but in reality, they are not, while False Negative represents the opposite situation.

Results and Discussion

In this project, we collected information from different studies on *Yucca gloriosa* monitoring in the study area for assessing the time- and cost-effectiveness of those methodologies and offering recommendations for management strategies.

Regarding methodologies employing UAV imagery, the expenses primarily involve the procurement of software for orthorectification, Agisoft Metashape, which amounts to approximately 200 €, exclusive of drone-related costs. Notably, other software utilized, including QGIS, PIX4DCapture, Orfeo ToolBox, and R, are open-source alternatives. The duration necessary for acquiring UAV imagery and generating orthomosaics over the 3-hectare expanse spans approximately one hour for both flight planning and execution, with an additional hour for orthomosaic generation. These procedures demand minimal human involvement, primarily centered around organizational tasks and conducting the UAV flight operations.

Regarding photointerpreting the distribution of *Yucca gloriosa* within the 3-hectare zone, our estimation indicates that a single expert operator would require approximately 40 hours of work, corresponding to an approximate cost of 2300 €, considering also the costs related to the drone operator.

The adoption of this methodology unveils challenges associated with human operator subjectivity and the shadow effect. Mitigating the influence of these challenges entails the option of conducting subsequent photointerpretation by the same operator and strategically scheduling UAV monitoring sessions between the hours of 11:00 and 14:00 to minimize the impact of shadows [4,25,30].

Conversely, the application of machine learning through Geographic Object-Based Image Analysis (GEOBIA) and the Random Forest approach requires less human intervention compared to the alternative methodologies under consideration. Upon acquisition of UAV imagery, the process of generating high accuracy prediction maps typically spans approximately three days, with related costs estimate to about 1200 €. Nevertheless, this methodology entails substantial computational resources and a foundational understanding of spectral variable combinations to effectively discern the target species.

On the other side, data pertaining to the expenditure associated with field monitoring of *Yucca gloriosa*'s cenosis within the scope of the LIFE project "DUNETOSCA" revealed considerable financial implications. Specifically, the project report delineated an estimated expenditure of 7500€ for botanical monitoring activities. This methodology provided phytosociological relevés, enabling the creation of vegetation maps and floristic inventories within Bufalina Reserve [32]. Alternatively, to ascertain the temporal demands associated with botanical monitoring, data was acquired from an ongoing project in which certain members of our team were involved. Within this context, the evaluation of *Y. gloriosa* distribution of 302 random points across the study area within the Bufalina Reserve engaged the expertise of three botanical specialists for approximately 5 hours. This calculation indicates that, at an average rate of 50 € per hour for each botanical expert, an expenditure of 750 € is necessitated for monitoring *Y. gloriosa* coverage across an area spanning 300 m^2, which corresponds to 1 % of the whole study area. Beyond the substantial investments in time and human resources, field monitoring offers the distinct advantage of accurately identifying species and producing maps of exceptional precision (Tab. 1). Conversely, accessing certain unreachable areas poses challenges for field monitoring, a limitation effectively circumvented by the utilization of Unmanned Aerial Vehicles.

Table 1 – Comparison between costs and accuracy of three *Yucca gloriosa* mapping methodologies

	Costs	Time	Accuracy
Field monitoring	7500 €	500 hours	-
Photointerpretation	2300 €	42 hours	OA 0.95 | K 0.87 TSS 0.85 | BA 0.93
Machine learning	1200 €	20 hours	OA 0.97 | K 0.91 TSS 0.873 | BA 0.94

In summary, the selection of suitable methodologies for monitoring alien plant species in imagery relies primarily on their morphological, phenological, and spectral attributes, alongside image resolution [26]. Within coastal dune environments, the utilization of very high-resolution imagery is essential for distinguishing species within fragmented habitats and drives to high accuracy maps (Fig. 2). In this regard, Unmanned Aerial Vehicles offer the capability to acquire high-resolution images in a flexible and reproducible manner [16,22].

Figure 2 – Comparison between field, photointerpretation and machine learning monitoring of *Yucca gloriosa*.

Conclusions

In conclusion, through a comparative analysis of three mapping methodologies for the invasive alien plant *Yucca gloriosa* within a designated area on coastal dunes, it was determined that field monitoring is the most resource-intensive in terms of time and cost for generating accurate maps. Consequently, we recommend monitoring the distribution of the target species by strategically scheduling annual UAV flights to assess trends in its distribution over time. The methods exhibited high accuracy rates and cost reductions, rendering photointerpretation or machine learning more favorable alternatives to field monitoring. Nonetheless, we suggest that field monitoring could be used one-off and concentrating in small areas for assessing the accuracy of Remote Sensing.

An intriguing avenue for further exploration involves repeating both photointerpretation and machine learning processes on images acquired during different months. This approach aims to identify the most effective month for distinguishing *Yucca gloriosa*, considering its distinctive phenological and physiological characteristics, which may enhance its differentiation from the surrounding environment.

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CRYPTIC DIVERSITY OF THE WIDESPREAD SCORCHED MUSSEL *BRACHIDONTES PHARAONIS-VARIABILIS* SPECIES COMPLEX

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Abstract: The phenomenon of bioinvasions, when species spread beyond their native ranges, is widely studied in terms of biological and ecological characteristics of the species involved. However, some cases need taxonomic deepening due to misidentifications which often occur. The *Brachidontes pharaonis-variabilis* species complex, a mussel group, exemplifies these challenges. Originally from the Indo-Pacific region, the species *Brachidontes pharaonis* has successfully invaded the Mediterranean Sea. The true boundaries of its Indo-Pacific range are poorly understood, partly due to confusion with a similar species, *B. variabilis*. This morphological overlap complicates accurate distribution mapping. This paper emphasizes the need for integrative analyses and reports morphometric and genetic variability within the complex.

Keywords: Invasive Alien Species, Mytilidae, Mediterranean Sea, Geometric Morphometry, Genetic analysis

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Tiziana Curatolo, Matteo Battiata, Sabrina Lo Brutto, *Cryptic diversity of the widespread scorched mussel* Brachidontes pharaonis-variabilis *species complex*, pp. 179-187, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.15

Introduction

It is demonstrated that marine biodiversity can be drastically altered by invasive species producing new competitive behaviours or predatory-prey and trophic dynamics [13]. *Brachidontes pharaonis* (P. Fisher, 1870) is one of these; it is one of the most widespread invasive non-indigenous species in the Mediterranean coasts (Figures 1 and 2). This bivalve is a small Lessepsian mussel that has successfully colonised the basin following an immigration pathway through the Suez Canal from the Red Sea [16]. As for many other species, human activities have contributed to *B. pharaonis* dispersion in non-native areas via marine shipping and discharge of ballast water. The presence of this species has direct ecological effects on Mediterranean ecosystems, such as disruption of food chains or displacement of autochthonous mussels [14].

Brachidontes pharaonis is a euryhaline, eurythermal, general filter feeder and presents physiological plasticity which contributed to its expansion [15]. For these reasons, *B. pharaonis* represents a good model for studying the prerequisite conditions for successful colonisation [1, 8, 18, 19]. In the Mediterranean area, it is still in a phase of expansion and its presence is confirmed from east to west in different countries, such as Tunisia, French, Spain, Croatia, Italy, Greece, Turkey, Israel, Egypt, Malta, Slovenia [1, 5, 7, 11, 16]. In particular, the Sicilian Island, in the centre of the basin, seems to be a sort of "trap" for populations which successively disperse by marine currents [3, 16]; the species can there establish local populations that may guarantee the maintenance of the species in the Mediterranean Sea.

The great adaptability and colonisation behaviour are not the only characteristics of *B. pharaonis*. Regarding the Mediterranean area, previous analyses have already shown the co-existence of two mitochondrial haplogroups (M-type and L-type) detected within some sites of the Mediterranean Sea and Red Sea [1, 18, 19]. Moreover, the morphological variation within *B. pharaonis* is so high that the range boundaries are not still defined and are misidentified in regions outside the putative distribution area [3]. Such misidentifications corroborate the difficulties in the taxonomic diagnosis [23]. Several studies in fact have documented the presence of *B. pharaonis* in the Persian Gulf, in Southeast Asia (Indonesia, Malaysia, and Thailand), and in the central Indian Ocean (Sri Lanka) [6, 24, 25]. Hence, we present herein a review of published genetic and morphological data as a supporting baseline for the taxonomic issues of the *Brachidontes pharaonis* + *variabilis* group.

Figure 1 – External and internal view of the valves of two specimens of *Brachidontes pharaonis*.

Figure 2 – Specimens of *Brachidontes pharaonis* in Dahab lagoon, Egypt, Red Sea.

The genetic and morphometric data

The great differentiation detected by molecular markers was the cause of the no longer accepted synonymy of *B. pharaonis* with *B. variabilis* (Krauss), the latter distributed in the Indo-Pacific region [23]. The genetic variation of *B. pharaonis* revealed that the *B. pharaonis* distribution is only limited to the Mediterranean Sea and the northern Red Sea region, as current genetic studies detected [3]. A

Maximum Likelihood tree has been constructed with mitochondrial COI sequences (Figure 3) retrieved from the literature. The phylogenetic tree (Figure 3) shows a great differentiation between sequences from the Red Sea and the Mediterranean area and sequences from the Indian and Pacific Oceans, which cluster in two more separated lineages. A valid example of probable misidentifications are individuals from Sri Lanka which were identified as *B. pharaonis* (Accession Numbers: AJ865780, AJ865781, AJ865786, and AJ865782) but are strongly grouped (99 bootstrap value) in a separate clade together with individuals from China.

The tree of Figure 3 corroborates the existence of three lineages, a finding that is also supported by previous geometric morphometric data of shells [6]. The identification of *B. pharaonis* is complicated. In a case, Swennen et al. [17] used bifurcation of radial ribs, inner margin crenulated on the posterior side, and the colour of the shells for the identification of the species in Thailand while Well et al. [23] suggested a misidentification of samples, which should be identified as *B. variabilis* species.

Consequently, different studies [4, 6, 9] have employed an integrated approach, combining genetic data with geometric morphometrics of valves. This approach aims to reinforce the identification of three lineages within the *Brachidontes pharaonis* + *variabilis* group: those from the Mediterranean and Red Sea, the Indian Ocean, and the Pacific Ocean. In agreement with Curatolo [6] the Geometric Morphometric analysis showed a high shape variation. Here the analysis by Curatolo [6] of the relative warps is reported. The relative warps are principal component vectors of the partial warps, variables generated for thin-plate spline transformations, and were used to describe the major trends in shape variation among specimens [6]. The first relative warp (RW1) explained 45.88 % of the variance, the second (RW3) was 19.78 % and the third relative warp (RW4) 14.98% (the total explained variance was 80.64 %; Figure 4). The thin-plate spline deformation grids shown in Figure 3 (A and B) represented the most extreme shapes in that variation. RW1 included individuals based on the variation in dorsoventral height of the shell, RW2 individuals according to the variation in the ventral margin of the shell (more or lesser concave), while, lastly, RW3 clustered individuals showing the variation in the anterodorsal margin (ranging from angular to curved) (Figure 5).

It is noteworthy that the three lineages align with marine biogeographical provinces [21]. The Red Sea, Western Indian Ocean, and Indo-Polynesian areas are identified as provinces due to their high levels of endemism and isolation from other provinces by barriers [21]. This pattern is also observed in other globally distributed species [2]. The three detected lineages correspond to these provinces: *B. pharaonis*, originating from the Red Sea, has invaded the Mediterranean Sea; *Brachidontes* cf. *variabilis* from Madagascar and South Africa belong to the Western Indian Ocean province; and *B.* cf. *variabilis* samples from Sri Lanka and China are included in the Indo-Polynesian province.

Records of *Brachidontes pharaonis* or *B.* cf. *variabilis* from the Indian Ocean and western Pacific regions could belong to three distinct entities which require thorough investigation, and the boundaries of the *B. pharaonis* range need to be clearly delineated, as they are not yet well-defined.

Figure 3 – Maximum Likelihood tree built from COI sequences using published data [6, 12, 17, 19]; a bootstrap value > 0.8 is shown. Location is reported on the name of the tips. The sequences were aligned in BioEdit [10] using ClustaW [20]. The ML analysis was conducted using default parameters for 10000 bootstraps in IQ3 portal [22].

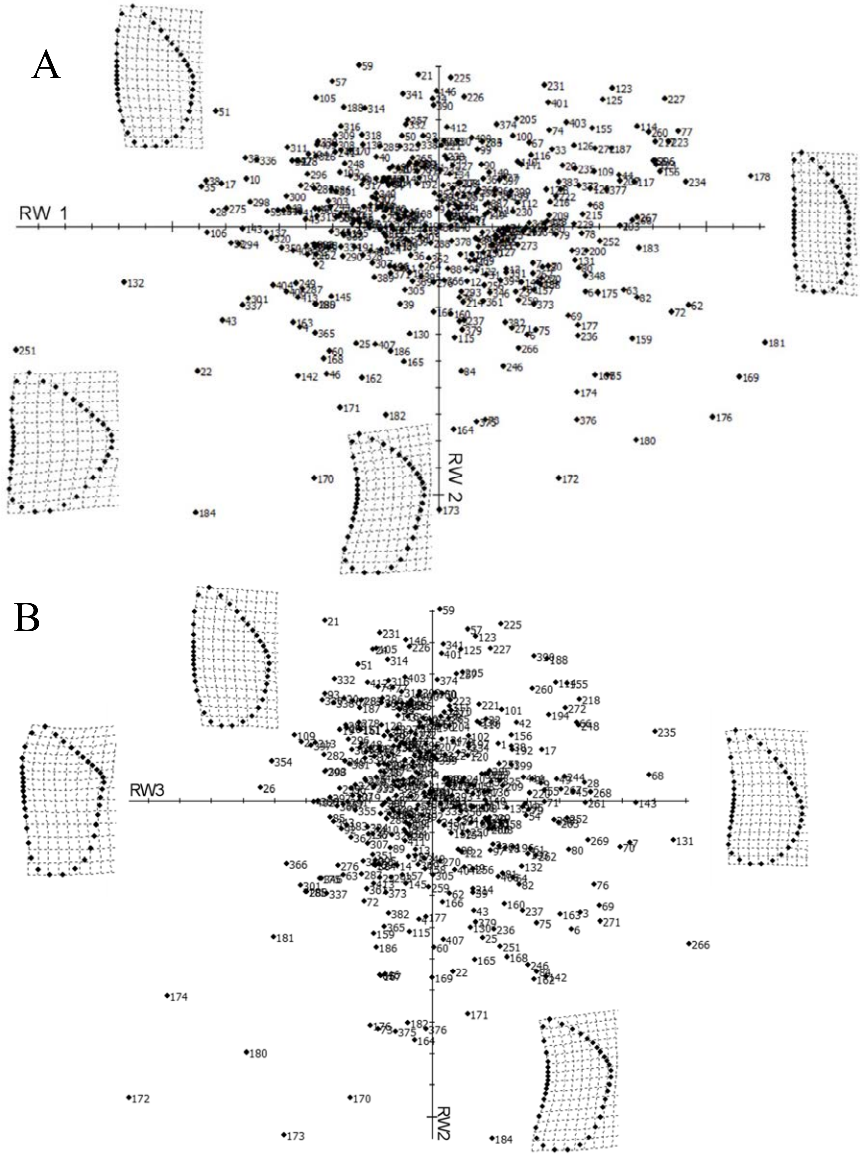

Figure 4 – (A) Scatterplots of the two first relative warp scores obtained from the Relative Warp Analysis (RWA) of the shape of external morphological structures. (B) Scatterplots obtained of the second relative warps scores respect to the third relative warps scores. Plot resulting from the analysis of the shell shape shows deformation grids relative to the axis. (Courtesy Curatolo [6]).

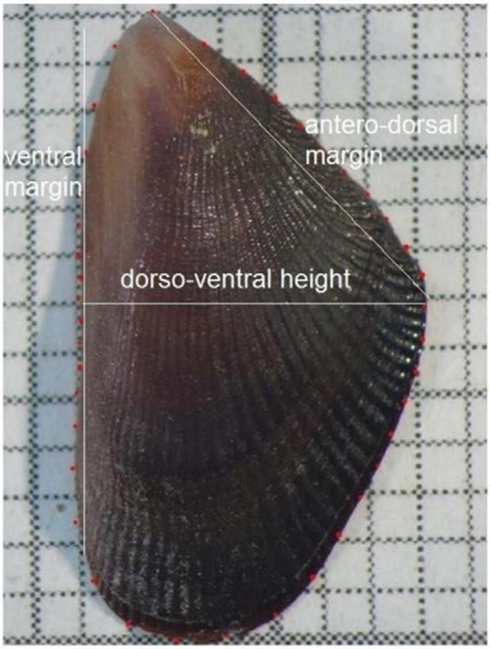

Figure 5 – Illustration of the variable portions of the valve shell in *Brachidontes sp.*

Conclusion

Reports of *B. pharaonis* from regions outside its known range should be treated with caution. At the same time, the *B. variabilis* data from the Indian and Pacific Oceans indicated potential cryptic species. The identification of the natural limits of their maximum range area is one of the most important goals to correctly interpret the presence and dispersion of the species. Additionally, errors in taxonomic identification can undermine good monitoring, creating confusion for the management of the invasive species. This review highlighted the importance of integrative taxonomic approaches to solving various issues about this species complex.

Acknowledgements

Project partially funded under the National Recovery and Resilience Plan (NRRP), Mission 4 Component 2 Investment 1.4 — Call for tender No. 3138 of 16 December 2021, rectified by Decree n.3175 of 18 December 2021 of the Italian Ministry of University and Research funded by the European Union —

NextGenerationEU; Project code CN_00000033, Concession Decree No. 1034 of 17 June 2022 adopted by the Italian Ministry of University and Research, CUP D33C22000960007 and CUP B73C22000790001, Project title "National Biodiversity Future Center — NBFC".

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ANALYSIS OF THE AMPHIPOD SYNTAXON ON HARD BOTTOMS ANTI-TRAWLING STRUCTURES

Michela De Simone, Anna Di Cosmo, Ornella Nonnis, Gianluca Franceschini, Barbara Catalano, Paolo Tomassetti, Laura Ciaralli, Eleonora Monfardini, Benedetta Trabucco

Abstract: This work is part of an environmental monitoring project conducted by Ispra since 2008, with the installation of two marine cables between the Lazio coast and Sardinia. Following the deployment of anti-trawl tripods, since 2017, a new Ispra monitoring plan was established to assess the integrity of the marine environment. The anti-trawl tripods have been periodically analyzed to examine various aspects of the marine area where they have been installed, including any changes in faunal and algal biodiversity resulting from the introduction of artificial structures. This study involves observing recruitment on the anti-trawl barriers to assess the colonization of artificial substrates introduced into the marine environment.

Keywords: Crustacea Amphipoda; sea environmental monitoring; recruitment; hard-bottom; Sardinia Sea

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Michela De Simone, Anna Di Cosmo, Ornella Nonnis, Gianluca Franceschini, Barbara Catalano, Paolo Tomassetti, Laura Ciaralli, Eleonora Monfardini, Benedetta Trabucco, *Analysis of the* amphipod syntaxon *on hard bottoms anti-trawling structures*, pp. 188-196, DOI: 10.36253/979-12-215-0556-6.16

Introduction

The high demand for energy for domestic use has resulted in the increasing of human infrastructure such as electricity cables. These structures have been laid during last decades both on Italian onshore, both on Italian off-shore, on the seabed. Often it had been necessary to lay these cables between the Italian Continent and the major Italian Island such Sardinia. The realization of such structures could generate different impacts both on the water column and on the sea bottom. Up to now several studies have proved that offshore activities can induce changes in the characteristics of sediment regarding these off-shore structures. In particular, the presence of these constructions might have some sort of impact on benthic communities inhabiting the surrounding seabed. The variations in sediment physical features (e.g. sediment grain-size, sedimentation rates) might determine qualitative and quantitative changes in the structure of soft-bottom benthic communities living immediately around the installations. [1; 3; 4; 7; 8; 9; 10; 11; 12; 13].

Our work is a part of a broader environmental monitoring initiative conducted by the Institute for Environmental Protection and Research (ISPRA) within the SAPEI Project, implemented by Terna S.p.A. with the installation of two marine cables between the Lazio coast and Sardinia. During inspections conducted at various points along the cables, damage attributable to anthropogenic actions, likely illegal bottom trawling activities, was observed. Then, to safeguard the connection, protecting the cables from potential illicit activities while simultaneously promoting the protection of existing ecosystems, since 2017 tripods, artificial anti-trawling barriers, were introduced. Following the deployment of anti-trawl tripods, a sub-monitoring plan was established always by Ispra to assess the integrity of the marine environment. The anti-trawl tripods have been periodically analyzed to examine various aspects of the marine area where they have been installed, including any changes in faunal and algal biodiversity resulting from the introduction of artificial structures. This study involves observing recruitment on the anti-trawl barriers to assess the colonization of artificial substrates introduced into the marine environment. In general, the complete benthic community structure was investigated, in order to have a biological lecture of the marine ecosystem. These assemblages were studied since 2018, and then up to October 2022. In particular, here we present the amphipod species sampled in eight stations. univariate and multivariate analyses were conducted in order to assess both the qualitative and quantitative structure of the syntaxon amphipoda assemblages. the work has focused on amphipod syntaxon as a partial descriptor of the community and, therefore, a tool for assessing the current state of the ecosystem. it was very interesting from an ecological point of view to observe that from the very beginning (2018) to 2022 there had been an evolution of community, in term both of number and species richness, also looking at the differentiation of niches and ecology of sampled species. Many of them showed an ecology both linked to hard bottom and to sandy soft-bottom. Some speciesmen are more linked to bottom more exposed to the light, while others to the dark side of tripods. Furthermore, elaborating Amphipoda structure with multivariate statistics, we can see that a partial differentiation began to exist among upper stations and down stations, indicating then the preference of different species and then to different speciesmen just described above, in relation to the light along the water column. These submerged artificial structures were analyzed seasonally to assess potential changes in the marine area where they were installed. Over the years, anti-trawling tripods have proven effective in reducing the impact of bottom trawling and promoting marine biodiversity. However, their success largely depends on their ability to attract and support colonization by marine species. This colonization process, known as recruitment, is crucial for the restoration of marine habitats and the establishment of resilient marine communities. Our work then focuses on observing recruitment on anti-trawling barriers to evaluate the colonization of artificial substrates introduced into the marine environment. In particular, the research involved the identification of amphipod species collected by the means of scuba diving, in eight selected samples. Amphipods emerge as one of the most diversified and fascinating groups of crustaceans inhabiting marine waters and can serve as a partial descriptor of the community, providing a tool to assess the current state of the ecosystem.

Material and methods

Sampling strategy, field and laboratory procedures, data elaboration

During the whole project the colonization of the artificial substrates released into the marine environment was analyzed through two methods: direct and indirect, during the various phases of succession of the reef population as indicated by the FAO guidelines for the monitoring of artificial reefs in the Mediterranean Sea [5].

In consideration of the different types of substrates and environments present in the reefs, a sampling plan was designed which envisages the study of the population in two bathymetric bands: SUPERFICIAL BAND (UP photophilous and DOWN (DW) sciaphilous)) between 10 and 15 m; and DEEP BAND, between 20 and 30 m (UP photophilous and DOWN (DW) sciaphilous)).

For each band, an artificial barrier (tripod) was chosen, selected on the basis of its representativeness of the average environmental conditions of the area in which it was positioned: for the superficial band 1 tripod (station) in Punta Tramontana (PT_2_F), and 1 tripod (station) in Fiume Santo (FS_6_C); for the deep band 1 tripod (station) in Punta Tramontana (PT_18_F) , and 1 tripod (station) in Fiume Santo (FS_61_C), for a total of 2 stations for area. Then, for each band 2 samples were taken for each station: 1 (UP) in a horizontal position on the tripod, and 1 (DW) in a vertical position on the tripod. Totally, then, in the Punta Tramontana area 1 station x 2 samples at the superficial band and 1 station x 2 samples at the deep band were performed, as well as in Fiume Santo site, for a total of 4 stations x 2 areas = 8 samples. for the deep band (Table 1).

Table 1 – Sampling Stations and Samples in Punta Tramontana and Fiume Santo areas.

SAMPLING STATIONS	
SUPERFICIAL BAND	**DEEP BAND**
1 horizontal station:	**1 horizontal station:**
PT_2_F_UP_1_23	**PT_18_F_UP_3_23**
1 vertical station:	**1 vertical station:**
PT_2_F_DW_2_23	**PT_18_F_DW_4_23**
1 horizontal station:	**1 horizontal station:**
FS_6C_UP_5_23	**FS_61_C_UP_7_23**
1 vertical station:	**1 vertical station:**
FS_6C_DW_6_23	**FS_61_C_DW_8_23**

The underwater activities for the direct sampling were performed by an OTS (*Operatore Tecnico Subacqueo*, that is *Underwater Technical Operator*) Researcher from ISPRA supported by OTS from the Oceansub company contracted specifically for this activity. In each station, the ISPRA underwater researcher took steps to directly collect the biological samples by completely manual grating of all the material adhering to the surface of the reef, collected using an air operated suction suppler of a surface enclosed in a 20 x 20 cm square, operated by an OTS diver from Oceansub. All samples were stored in 80% denatured alcohol solution. Here we do not present materials and methods used for the indirect sampling, since we decide to analyze only the portion of benthic community sampled by the means of direct method.

Qualitative and quantitative analysis of macrozoobenthic communities has been carried out in the laboratory [6], and all individuals were classified and taxonomically recognized, down to the lowest possible taxonomic level, i.e. the species. Amphipoda were all separated from all other taxa. The structure of the Amphipoda community was assessed by considering both species and individual organisms to characterize the biocenotic traits of the study area. Subsequently, we subjected the collected data to statistical analysis to gain deeper insights into the population structure and to detect any spatial and temporal variations. Univariate analyses were performed: different structural parameters and ecological indices were employed: Total abundance N, Total species richness S, the Shannon-Wiener

Specific Diversity Index H'; Pielou index J. Abundance data underwent analysis using advanced multivariate statistical methods. A multivariate assessment was carried out based on quantitative matrices featuring "taxa x stations". This involved the application of non-metric Multidimensional Scaling (nMDS) and Cluster analysis utilizing the average linkage algorithm. These analyses relied on the Bray-Curtis similarity index and were conducted using Primer 6.1.6 software [2].

Results and Discussions

Here we present results regarding only Amphipoda sampled by the direct method.

Qualitative-quantitative analysis

The analysis of the qualitative and quantitative composition, including the number of species and their abundances, within the eight stations under consideration, reveals the following patterns: the number of species appears similar between the stations of *Punta Tramontana* and those of *Fiume Santo*, with peaks detected in station FS_61_C_DW_8_23 followed by station PT_18_F_DW_4_23, while the lowest values were observed in stations FS_6C_DW_6_23 and FS_6C_UP_5_23 (both sciaphilous and photophilous). As regards abundance, it is possible to observe a greater variation between the stations considered, with the largest peak being observed in the FS_61_C_DW_8_23 station while the smallest one was observed at the PT_18_F_UP_3_23 station (Fig. 1).

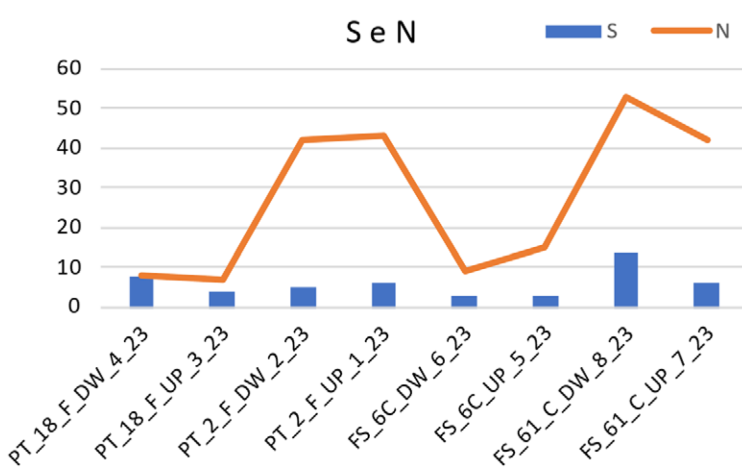

Figure 1 – Qualitative-quantitative amphipods composition in the 8 studied stations. S = Number of Species; N = Number of Individuals.

Structural indices

Regarding species richness, for the *Punta Tramontana* stations the highest value was found at station PT_18_F_DW_4_23, followed by station PT_2_F_UP_1_23, and then station PT_2_F_DW_2_23. The lowest value was identified at station PT_18_F_UP_3_23. For the Fiume Santo stations the species richness values are similar for stations FS_6C_UP_5_23 and FS_6C_DW_6_23, but increases slightly for station FS_61_C_UP_7_23. The highest value ever, among all the eight stations considered, was found in station FS_61_C_DW_8_23. The Evenness Index shows a similarity between the stations of the same reef. In particular, in the PT_2_F_UP_1_23 and PT_2_F_DW_2_23 stations (both sciaphilous and photophilous), a high Evenness Index is noticeable, with the maximum value reached at station PT_2_F_UP_1_23. The stations of reef 18_F (PT_18_F_UP_3_23 and PT_18_F_DW_4_23), on the other hand, exhibit significantly lower Evenness Index values, especially concerning station (PT_18_F_UP_3_23.

Regarding *Fiume Santo* stations the smallest values were detected in stations FS_6_C_DW_6_23 and FS_6_C_UP_5_23. The evenness index instead reaches high values in stations FS_61_C_DW_8_23 and FS_61_C_UP_7_23. The Margalef's species richness index is quite similar among the stations PT_18_F_UP_3_23, PT_2_F_DW_2_23, and PT_2_F_UP_1_23. A more diversified value for this index was instead found for station PT_18_F_DW_4_23, where the highest value of Margalef's species richness index was identified. The Margalef index is substantially very similar in the Fiume Santo stations, with a slightly higher value for the FS_61_C_DW_8_23 station. Regarding the Pielou index, the values are very similar between the counterparts (sciaphilous and photophilous) of the two reefs. The index shows similar values between the Punta Tramontana and Fiume Santo stations. There are no particular variations in this value even between the two 6_C (FS_6_C_DW_6_23 and FS_6_C_UP_5_23) stations and the two 61_C (FS_61_C_DW_8_23 and FS_61_C_UP_7_23) stations.

The Shannon-Wiener Specific Diversity Index in Punta Tramontana showed very similar values between the stations PT_2_F_UP_1_23 and PT_2_F_DW_2_23, although it is slightly higher in station PT_2_F_UP_1_23, while the highest Shannon-Wiener Specific Diversity Index in this area was found in station PT_18_F_DW_4_23. The lowest value among Fiume Santo stations was detected in the FS_6_C_UP_5_23 station, while the highest in the FS_61_C_DW_8_23 station. As for the Simpson's Diversity Index, in Punta Tramontana, its value is very similar between the shaded and well-lit stations of the same reef. Even for the Fiume Santo stations there are no particular differences in the value of this index (Fig. 2).

The nMDS analysis based on the abundance data showed the presence of 2 main groups. The dendrogram in Figure 3 reveals a similarity of approximately 62 % between the PT_18_F_UP_3_23 and FS_6_C_DW_6_23 stations. The station that shows the greatest dissimilarity with all the other stations is FS_6_C_UP_5_23.

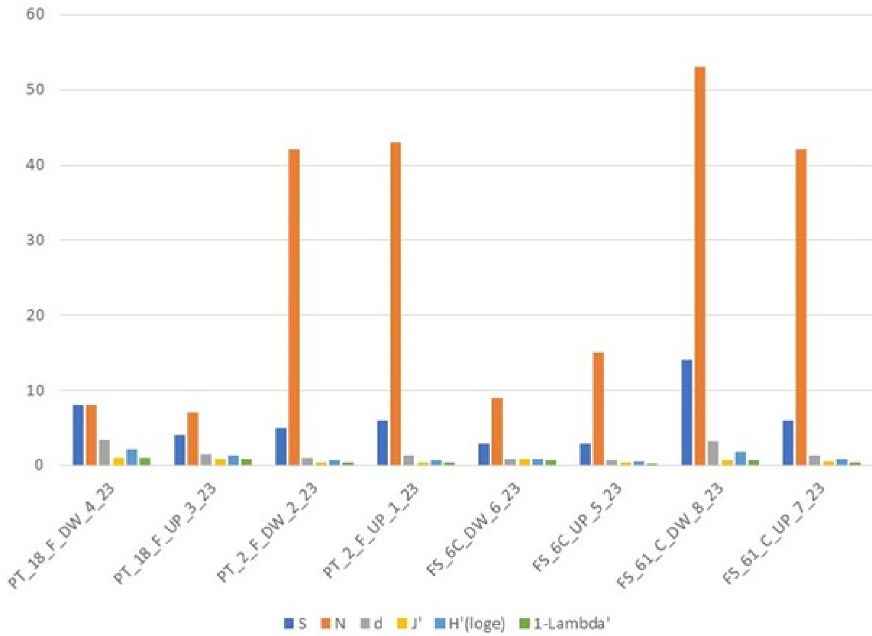

Figure 2 – Comparison of structural indices in the 8 studied stations. S = Number of Species; N = Number of Individuals; d = Margalef Specific Richness; J' = Pielou Equitability; H' = Shannon Diversity; 1 – lambda = Simpson Diversity.

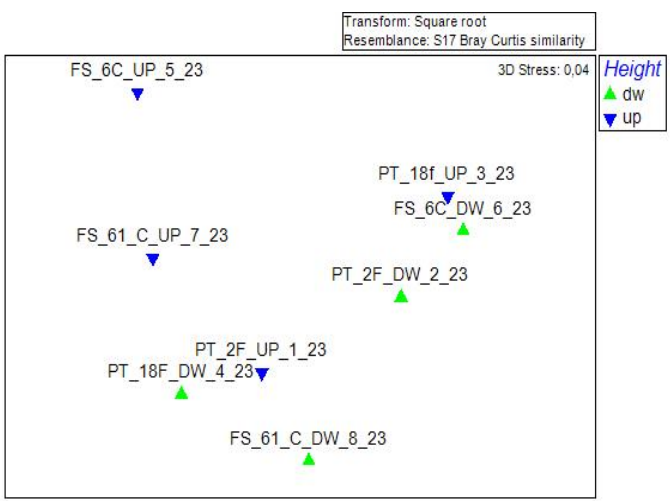

Figure 3 – nMDS *scaling* analysis in the 4 stations (8 samples). Stations were differentiated using the *factor* of *height* (depth).

Conclusions

Totally Amphipods emerge as one of the most diversified and fascinating groups of crustaceans inhabiting marine waters and can serve as a partial descriptor of the community, providing a tool to assess the current state of the ecosystem.

The data obtained by the sample analysed confirm findings from similar studies conducted in other coastal areas and highlight the challenges in predicting the processes and timing of colonization by macrobenthic organisms.

Moreover, the data obtained indicate a well-established state of colonization of the anti-trawl barriers, progressing towards a climax stage. The vagile fauna primarily consists of small-sized organisms that inhabit the algal mats. Changes in the abundance and composition of amphipod species over time on the artificial reef provide valuable and essential insights into the ecology of these species and their intra/interspecific relationships.

This work has confirmed what has already been demonstrated by similar studies regarding the utility of anti-trawl barriers as artificial habitats, attracting a wide range of organisms, from small invertebrates to fish, and therefore have positive effects on fish repopulation and biodiversity. Tripods were indeed introduced as invasive structures designed to prevent the passage of trawl fishing gear on the seafloor, thus protecting the habitats and species living there. Monitoring activities remain highly relevant because the evolution of the colonizing population needs to be studied and evaluated over time.

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MONITORING *TOUMEYELLA PARVICORNIS* (COCKERELL) (HEMIPTERA: COCCIDAE) INFESTATION ON COASTAL AND URBAN *PINUS PINEA* L. STANDS THROUGH INTEGRATION OF REMOTE SENSING AND *IN SITU* DATA

Valentina Falanga, Saverio Francini, Francesco Parisi, Bruno Lasserre, Gherardo Chirici, Marco Ottaviano, Marco Marchetti

Abstract: Urban forests are particularly significant as they enhance quality of life by fostering social connections and improving physical and mental health. They also reduce pollution, lower heating and cooling costs, increase real estate values, and help mitigate climate change. Effective management and maintenance of urban forests are crucial to ensure these benefits continue. Consequently, the management of urban green areas is even more important, increasingly subjected to external pressure, yet they represent the few remaining comfortable areas in the city and guarantee the maintenance of urban biodiversity. There are numerous potential disturbances that can jeopardise the existence of urban green areas. This study focuses on the urban area of the city of Rome, where the *Pinus pinea* population is attacked by the scale insect *Toumeyella parvicornis*, which is undermining its existence. This research studies PlanetScope images from 2019 to 2023 with the objective of evaluating the effectiveness of remote sensing in studying this phenomenon.

Keywords: Pests, Urban forests, Monitoring, PlanetScope

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Valentina Falanga, Saverio Francini, Francesco Parisi, Bruno Lasserre, Gherardo Chirici, Marco Ottaviano, Marco Marchetti, *Monitoring* toumeyella parvicornis *(cockerell) (hemiptera: coccidae) infestation on coastal and urban* pinus pinea *l. Stands through integration of remote sensing and* in situ *data*, pp. 197-207, DOI: 10.36253/979-12-215-0556-6.17

Introduction

Based on CORINE Land Cover plus (CLC+) Backbone 2018, a geospatial component of the CLC+, (EEA, 2022), the Italian area occupied by needle-leaved trees is approximately 1 650 000 hectares. Of these, about 240 559 hectares are classified as Mediterranean pine forests, divided between *Pinus pinaster Aiton* forests (64 701 ha), *Pinus pinea L.* forests (48 123 ha), and *Pinus halepensis Mill.* (114 713 ha), according to the 2015 INFC inventory (INFC2015) Throughout the Mediterranean area stone pine forests *P. pinea* are distributed in a fragmented manner, covering approximately 650 000 hectares and ranging from sea level to an altitude of 1000 meters. *P. pinea* is particularly concentrated on the Iberian Peninsula, as well as the coasts of France and Italy [1]. Maritime *P. pinea* forests (the ones located in coastal areas) are often found near heavily developed areas. This is due to historical factors that encouraged the planting of pine forests near marshy areas to enhance their soils and protect inland crops [2]. Additionally, the greater concentration of land consumption and human activities along coastal areas also contributes to this phenomenon [3]. Pine forests, mainly the ones in coastal areas, are threatened by several factors, anthropic (tourism, infrastructure and building activities), biotic (parasite attacks, nutrient unavailability) [4] [5] and abiotic (fire, drought, structural problems). In Rome, *P. pinea* forests are under threat from the *Toumeyella parvicornis* (Cockerell) (Hemiptera: Coccidae). The origins of this scale species are from North America and then it expanded to the Caribbean region and Europe [6]. It was first detected in Italy in 2014 (specifically in the regions of Abruzzo, Campania, Lazio and Apulia) and is under the official control of the EFSA Panel on Plant Health. The alien pest produces sticky honeydew related to feeding activity, this causes the development of sooty moulds that cover branches and needles. Attacked plants suffer yellowing, reduced growth, phylloptosis, decline and death [7]. In addition to the spread of this alien species across Europe due to globalized world trade, global warming contributes to its proliferation [8]. At the end of 2014, the tortoise pine scale *T. parvicornis* was recorded in Italy (Naples) for the first time [9]. In 2018, *T. parvicornis* was also reported in Rome and led to the decay and death of many plants around central and south Italy [10]. In this study, PlanetScope imagery was trialed for urban forest monitoring due to its ability to offer reliable, detailed images, which higher resolution satellites like Sentinel-2 could not provide due to mixed pixel effects.

The aim of this study is: i) to test the investigation sheet employed in the ground surveys; ii) to evaluate the effectiveness of the PlanetScope satellite constellation images to monitor damages caused by the attack of *Toumeyella parvicornis* on *Pinus pinea* in Rome; iii) to identify the advantages and criticalities of monitoring with high resolution satellite images forest disturbances occurring in urban areas.

Materials and method

The municipality of Rome is the area where the study is being conducted. It has a public space incidence of 3.7 %, approximately 48 km^2 [11], allocated among equipped green areas, historical archaeological parks, and large urban parks.

Moreover, Protected Natural Areas and Nature Reserves fall partially within the municipal territory. A preliminary analysis revealed that the large historic villas had the highest concentration of *Pinus pinea*. However, some public parks and other green areas were also included in the study: in these green spaces more uniform coverage of the same arboreal species can be found. Considered areas were chosen to cover different quadrants of urban territory, and they also respond to different characteristics: the density of crown coverage, homogeneity of species, and the dimension of crown coverage. Sites for analysis are selected inside the area delimited by Ring Road A90, more densely populated and urbanized.

Figure 1 – Sites for surveys chosen inside the area delimited by Ring Road A90.

Surveys were conducted between June and August 2023 at the selected sites. Each inspection entailed, using the Qfield app (Figure 2), the georeference and completion of the identification sheet for each individual plant.

In this study the method used for assessing tree condition is a qualitative method: the variables were evaluated on a scale ranging from 'not degraded', 'little degraded', 'moderately degraded', 'very degraded' to 'completely degraded' but transposed numerically in percentage of degradation to facilitate subsequent analysis. The form includes five variables: two related to sooty mold (presence and quantity), two related to tree crown (desiccation and density), and one related to the overall vitality of the plant. The first four parameters were evaluated in percentage intervals of 0 %÷20 %, 20 %÷40 %, 40 %÷60 %, 60 %÷80 %, 80 %÷100 %; the last one, which pertains to the overall evaluation of the plant's health, was rated with a score ranging from 1 to 5.

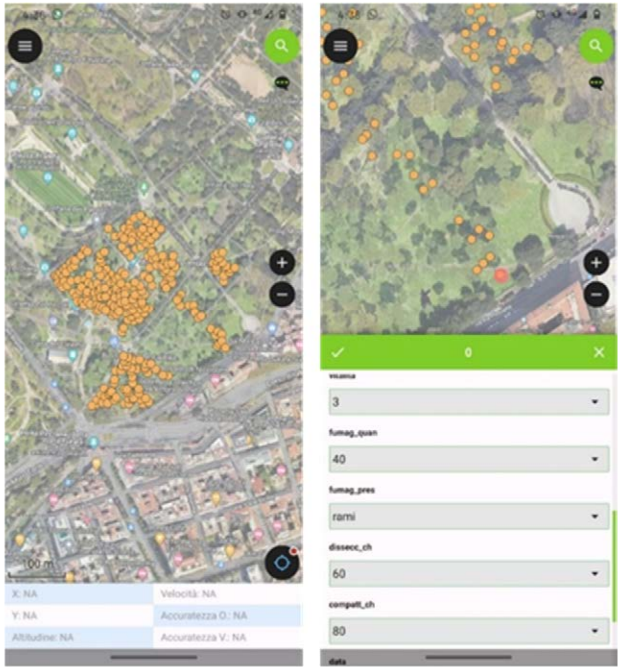

Figure 2 – Qfield app screen through which it was possible to georeference each point and fill in the corresponding evaluation form.

AREA:			DATE:	
Overall plant vitality:				
1	2	3	4	5
notes:				
Sooty mold presence:			rami	tronco
Sooty mold quantity:				
20%	40%	60%	80%	100%
notes:				
Tree crown desiccation:				
20%	40%	60%	80%	100%
notes:				
Tree crown density:				
20%	40%	60%	80%	100%
notes:				

Figure 3 – Evaluation sheet used for surveys. This sheet was digitalised and filled through the app Qfield

Table 1 – A list of the areas visited, accompanied by dates of surveys and plants surveyed within each area.

Name of area	Number of surveyed trees	Surface	Date of survey
Parco degli acquedotti	130	240 ha	16-29/06/2023
Villa Ada	30	160 ha	21/06/2023
Parco Don G. Alberione	16	0.7 ha	23/06/2023
Villa Borghese	340	80 ha	21/06 - 29/07 - 27/08/2023
Area verde via D. Campana	10	2.4 ha	07/06/2023
Via delle Terme di Caracalla	106	600 m	17/06/2023
Parco G. Sbragia	47	4 ha	23/06/2023
Parco E. Corizza	16	4.2 ha	06/06/2023
Villa Glori	202	23 ha	21/06 - 22/07/2023
Villa Lazzaroni	37	6.5 ha	18/06/2023
Parco Papacci	49	11 ha	10/06/2023
Villa Pamphili	574	185 ha	27/06 - 11/07 - 23/07 - 28/07 - 10/08/2023
Parco Petroselli	19	13 ha	07/06/2023
Parco Don Giovanni Scorza	40	1 ha	16/06/2023
Pineta Sacchetti	331	5 ha	27/06 – 08/08/2023
Trees along the road in the Saxa Rubra area	41	220 m	10/06/2023
Giardino Aldo Tozzetti	7	2.5 ha	07/06/2023
Parco Tor Tre Teste	28	54 ha	07/06/2023

The fully digital data recording methodology enables direct use of these data on specific software (Qgis and Google Earth Engine). As can be seen in Table 1 the number of plants in selected areas is variable, as is the surface of each area.

As the insect has infested all green areas of Rome, a control area was established outside the city in a section of the San Rossore pine forest, that had not yet been attacked by the insect.

In this study, we used PlanetScope nano-satellite images acquired between 2019-07-15 and 2023-07-15 and including 12 bands: four spectral bands (3 m spatial resolution) and eight quality bands. These images derive from the second generation of PlanetScope satellites (PS2.SD), available from 2019. The four spectral bands are:

Blue	464 ÷ 517 nm
Green	547 ÷ 585 nm
Red	650 ÷ 682 nm
NIR	846 ÷ 888 nm

The height quality bands were used to mask out clouds and noise from the images. Specifically, the height quality bands include the following information: “Band 1: clear mask; Band 2: snow mask; Band 3: shadow mask; Band 4: light haze mask; Band 5: heavy haze mask; Band 6: cloud mask; Band 7: confidence; Band 8: unusable data mask” [12]. Images were coregistered using the PlanetScope coregistration tool, which allows for spatial alignment of a series of images in a specified time series. The order, and thus the coregistration, the clipping, and the downloading of the imagery was performed in sequence for the 21 different study areas (Figure 1). This was important as to properly apply the coregistration tool there must be a consistent overlapping between different PlanetScope scenes and thus small study areas are needed. The final resulting number of downloaded coregistered and clipped imagery was 30 481.

A selection of areas, for subsequent analysis, was made based on the number of plants present in each area to ensure a sufficient sample size for defining area characteristics. The threshold for selection was 40 plants. For a preliminary study three areas were considered to test the process, calculated between August 2021 to August 2022. Once the band values had been obtained for each point surveyed, the vegetation indices were calculated. The results were aggregated by area, in order to have a single value for each site. First, a comparison was made between some of the most commonly used indices for detecting vegetation disturbances, based on the availability of the bands provided by PlanetScope [12]. The following indices were calculated: NDVI ($(Nir - R) / (Nir + R)$); RDVI ($(Nir - R) / (Nir + R)^{0.5}$); SAVI ($(1 + L) x (Nir - R) / (Nir + R + L)$ where L=0.5); and SIPI ($(Nir – B) / (Nir + B)$).

Although all the indices showed the same trends (except for SIPI), RDVI was the most effective in highlighting differences between chosen areas. Therefore, it was chosen for successive analyses. For the definitive study, the RDVI was calculated for the longest possible period permitted by PlanetScope images, spanning from July 2019 to July 2023, across all selected areas.

The index’s behavior over time was analysed by aggregating the data monthly, averaging the monthly values of all the plants belonging to the area considered. This level of aggregation was chosen in order to allow a more immediate comprehension of the index trend. When aggregating at a daily level, making the daily average for each plant belonging to the area, the data oscillation is too high, making it more complex to visualise the trend.

Figure 4 – Images of some areas: a) medium health status (Villa Borghese), b) bad health status (Pineta Sacchetti), c) branch with *T. parvicornis*

Results

The graphs below show the results of the preliminary study in which 3 areas were analysed over a 12-month period. As mentioned above, the use of RDVI was chosen because of its ability to better discriminate the differences between the areas.

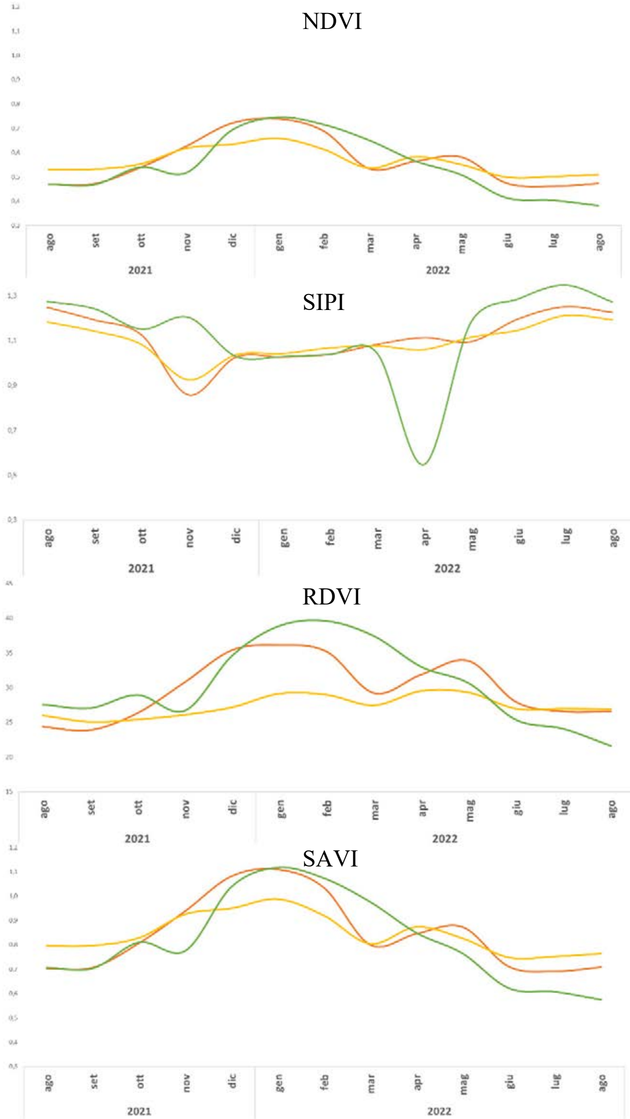

Figure 5 – Preliminary study on three areas to test the effectiveness of indexes: Pineta Sacchetti (green), Villa Glori (yellow) and Villa Borgese (orange). The evaluation period is 12 months (August 2021 – August 2022).

In the second phase of the study, the index was analysed across all areas surveyed. Figure 6 illustrates the average value for all areas, treated as a single zone, which declines during the spring-summer period each year.

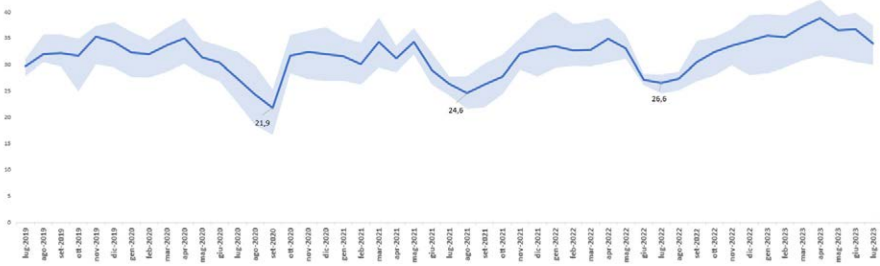

Figure 6 – Average RDVI of visited areas (gray part: range of maximum and minimum values assumed by the index)

The development (Figure 7) of the individual areas (shown in grey) and the selected control area were also examined. It is evident that the index trend of the control area differs from that of the areas attacked by *Toumeyella*; it does not exhibit a pronounced decline during the summer months, maintaining a relatively consistent level of activity. Over the considered period, numerous felling operations have been carried out, particularly of dead trees. This is due to the risk that trees in urban areas represent to public safety [13]. In the surveyed areas, a total of approximately 250 dead and cut trees were counted. These situations were, however, excluded from the analysis, to ensure that the described trend is not influenced by them.

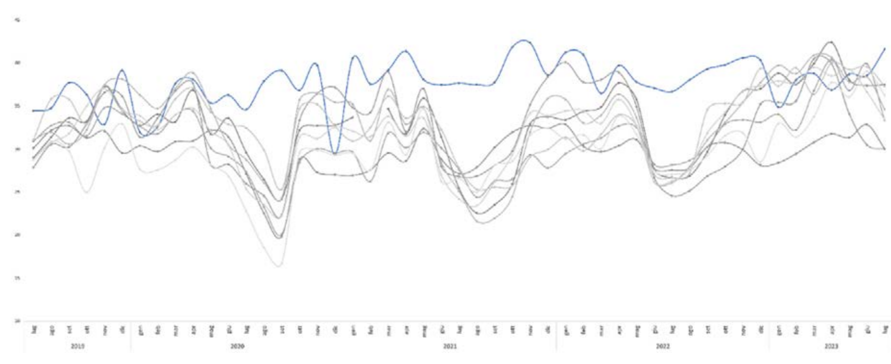

Figure 7 – Average RDVI of each visited area (gray) and control area (blue).

Discussion

In order to gain insight into the trend of the RDVI index of the attacked areas, it is essential to consider the ovideposition periods of *Toumeyella parvicornis*. As Garonna P. observe, three ovideposition cycles occur, the first between the second half of April and May, the second between July and early August, and the last between September and November. Between late spring and early autumn, the pathogen attack is continuous and debilitating for the plant, which has no time to recover. This can be observed in the trend of the RDVI, which shows a dramatic drop between May and September in all the visited areas. The efficiency of remote sensing, as shown in previous studies [14,15], is proved by the evidence of data, that shows the consistent damage inflicted on plants during the aforementioned period. Extracting data from remotely sensed PlanetScope imagery, allowed the calculation of vegetation indices to assess plant health over a long period of time, as shown by D'Amico et al., Dalponte et al., Shi et al. [10,16,17]. Comparing healthy areas with areas attacked by the insect (an approach also used by Wulder [18]), it was found that the values in the first one, do not decrease over the period indicated but remain relatively stable throughout the time period analysed. This provides to accentuate the periods of decline in the attacked areas with greater clarity.

It can be observed even that the deterioration tends to gradually decrease over time. A comprehensive analysis of the data reveals that the index reached a value of 21.9 in 2020, 24.6 in 2021, and a minimum peak of 26.6 in 2022 (Figure 6). It is possible that this trend of lower peaks is due to the implementation of a massive endotherapic treatment campaign throughout the municipality of Rome since the autumn of 2020 [19]. Unfortunately, no information on the endotherapy cycles was available for this study, (including the type of products used and the timing of treatments). This information will be essential in order to better understand the results in more detail. It would also be beneficial to reflect on the observation period. It is recommended that the observations be extended to encompass the years preceding and following the attack, in order to facilitate a more accurate assessment of the dynamics. This final point is directly related to the necessity of identifying high resolution images that extend back in time to a sufficient extent.

Conclusions

This research was conducted to test the use of remote sensing in the monitoring of *T. parivcornis* in an urban area. It is, indeed, the first study on urban green areas in the city of Rome (if we exclude the ones on the Castelfusano pinewood) affected by the parasite, investigated through very-high-resolution satellite images. The study demonstrates the efficacy of vegetation indices to clarify the impact of *Toumeyella* on *Pinus pinea*. This was achieved through the utilisation of high resolution PlanetScope images, which enable the analysis of highly detailed data across 4 spectral bands. Additionally, the research underscores the significance of direct field assessment and the subsequent generation of a ground-truth layer, which serves as a pivotal foundation for the following remote sensing phase.

In order to effectively counteract the invasion of *Toumeyella parvicornis*, further studies in this direction are still required. As future developments, it would be interesting to develop a technique for identifying markers that allow for intervention before plant death occurs. The sharing by stakeholders of additional information about the plants' health prior to the attack and the timing of treatment cycles could enhance the interpretation of the phenomenon's dynamics. Moreover, continuing ground surveys annually will increase the database and knowledge of the current state of the plants, which is fundamental for refining remote sensing work and obtaining more accurate results.

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STABILITY OF EPIBIOTIC COMMUNITIES ON THE METAL SURFACES OF SHALLOW-WATER WRECKS IN THE MALTESE ISLANDS

Perla Galatolo, Patrick J. Schembri

Abstract: The epibiotic assemblages on three wrecks in Maltese waters were studied by taking photoquadrats on the metal hull of each wreck, and on nearby natural hard substrata for comparison. The taxon richness and cover area of the colonising organisms was quantified, and organisms were classified into functional groups based on structural features. Bare patches of hull surface were present on all wrecks and the epibiota occurred in a mosaic of assemblages. Taxon richness was higher on the hulls than on natural substrata. It is suggested that the wrecks have a disclimax community supported by disturbances, such as uneven sloughing of the corroding metal, resulting is a mosaic of patches at different stages of succession. The natural hard substrata showed a high proportion of tall arborescent forms compared to hulls, supporting the hypothesis of the impeded development of a climatic climax community on the wrecks. NMDS ordination showed that the three wrecks were distinguishable from each other based on the relative cover of the different functional groups.

Keywords: Disclimax, Succession, Infralittoral Rock, Colonisation, Functional groups.

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Perla Galatolo, Patrick J. Schembri, *Stability of epibiotic communities on the metal surfaces of shallow-water wrecks in the maltese islands*, pp. 208-217, DOI: 10.36253/979-12-215-0556-6.18

Introduction

In the oceans, the presence of artificial metal structures, including vessels, gives rise to new underwater habitats on the seabed. Occurrence of such structures can be attributed to historical events, as for example the First and Second World Wars, but in modern times, intentional scuttling has transformed defunct vessels ('wrecks') and other structures into popular diving sites, thereby boosting the tourism industry of coastal nations. In many countries, regulatory requirements demand the removal of hazardous objects, pollutants and harmful materials from the vessels, to safeguard the ecosystem from potential negative effects and to ensure safety of wreck divers. Additionally, site selection for scuttling takes into account ecological considerations, often focusing on areas with sandy seabeds devoid of attached macroscopic organisms [24].

Artificial reefs are submerged structures composed of natural or synthetic materials which serve to protect, enhance, or restore components of marine ecosystems [20]. Sunken metal vessels in the photic zone are commonly categorized as 'artificial reefs' by the general public, due to their tendency to attract a higher density of fish compared to the surrounding habitat. However, while epibionts may flourish due to the establishment of bacterial and microalgal communities which provide the foundation for new biomass on the metal surface, fish populations do not usually exhibit a substantial surge. Instead, fish often seek refuge within the extensive spaces of the wreck, leading to a redistribution of biomass, rather than a significant increase [3].

Despite their potential consequences, the ecological implications of scuttled vessels and shipwrecks remains understudied. In particular, research concerning the colonization of wrecks by sessile organisms and the subsequent ecological succession occurring on their surfaces, is notably lacking on a global scale, with a scarcity of published works focused on the Mediterranean region.

Microbial communities adhering to wreck surfaces initiate marine biofouling processes, and these biofilms provide an ideal substratum for the attachment and settlement of larval forms and spores of higher-order sessile organisms such as invertebrates and algae [22]. The development of a biofilm underwater involves a series of distinct and regulated stages which follows a specific sequence of chemical and biological events, although the exact mechanisms remain elusive [22]. Planktonic bacteria in seawater are thought to initiate the process by interacting with organic and inorganic particles on the metallic surface, thus laying the foundation for the initial community. Subsequently, these pioneering microorganisms facilitate the growth and reproduction of other bacterial colonies, leading to modifications in the surface characteristics of the substratum. This, in turn, facilitates the colonization by secondary microorganisms. The third phase involves interactions between established colonies and other free-living bacteria, ultimately resulting in the formation of an initial biofilm. Over time, this biofilm matures through antagonistic or symbiotic interactions with other existing bacteria, as well as the recruitment of additional colonizers [5].

The colonization and ecological progression on metal surfaces within marine ecosystems are dynamic processes influenced by an array of factors, including the physicochemical properties of the metal surface and environmental variables such as depth, temperature, nutrient levels, hydrodynamics, illumination, and water chemistry [2][11][16][23][25][27]. Moreover, physical interactions, seasonal fluctuations, and geographical differences further shape ecological succession on marine wrecks [1][4][15]. As a result, marine succession is a complex phenomenon that cannot be universally applied, even within a given geographical area [11][16]. While research into the ecological succession associated with artificial substrata in marine habitats has largely focused on objects submerged in the upper layers of the ocean (epipelagic zone) [4][10][12][13], there have been few investigations on the long-term temporal aspect of ecological succession on wrecks.

The formation of a bacterial film is a universal event; however, subsequent phases of the succession depend on the physicochemical characteristics of the environment, resulting in varying outcomes. For instance, Henschel et al. (1990), in their study conducted in South Africa, observed minimal settlement of algae during the initial three months of submersion. Subsequently, the algae were largely outcompeted by barnacles and other organisms such as bryozoans, mussels, hydrozoans, and polychaetes [12]. In contrast, López Garrido et al. (2015) documented a colonization sequence starting with algae and barnacles, where the former eventually outcompeted the latter, leading to an algal-dominated metal surface [16]. A study by Choi et al. (2006) in Japan revealed a sequence of diatoms preceding algae colonization on metal surfaces; this study also emphasized the role of seasonality and the recruitment of spores and other propagules from mature algae in close proximity to the study site [4].

In the existing literature, a significant gap remains in terms of the long-term monitoring of ecological succession on wrecks, spanning multiple years. Consequently, empirical evidence regarding the potential long-term changes within these communities is lacking. Nevertheless, some studies have evaluated the epibiotic diversity on wrecks submerged for decades [14][26]. These studies indicate that the principal groups of organisms that settle after microbes, such as algae, bryozoans and mussels, tend to persist over the long term, although the actual species and their coverage may undergo alterations over time. An increase in the structural complexity of epibiotic assemblages was observed on natural marine substrata as succession proceeds [6][7][8][21]. However, in contrast to terrestrial ecosystems, no definitive climax community appears to conclude the succession. Instead, the original colonisers, which may include algae, bryozoans, crustaceans and molluscs, tend to remain dominant throughout the succession, with potential changes in coverage and abundance among different organism classes over time, also due to variations in environmental conditions [11][23][25].

The present study aimed to examine the stability of epibiotic communities inhabiting the metal hulls of wrecks at different locations around the Maltese islands and to determine whether wrecks that have been submerged for an extended period exhibit consistent epibiotic assemblages among themselves and when compared to nearby natural hard substrata.

Materials and Methods

The investigations were carried out on three wrecks situated off the Maltese coast:

- MV 'Um el Faroud' located off Zurrieq at 35.8188° N 14.4492° E. The ship was scuttled in 1998 and originally measured ca 110m in length, but today the wreck has broken into two pieces. Currently the vessel lies at a depth of approximately 36 m.
- Patrol boat 'P29' located off Cirkewwa at 35.9885° N 14.3261° E. The ship was scuttled in 2007 and measures ca 52m in length; up to the present it is intact on the sea bed. Currently the vessel lies at a depth of approximately 34 m.
- MV 'Karwela' located off ix-Xatt l-Ahmar, Gozo, at 36.0168° N 14.2864° E. The ship was scuttled in 2006 and measures ca 50m in length, and up to the present it is intact on the sea bed. Currently the vessel lies at a depth of approximately 45 m.

In preparation for this study, recognition dives were conducted to identify optimal sections of the hull for assessment, considering factors like surface uniformity and verticality.

The sampling areas for hulls were determined based on the hull size: 1.5 m x 1.5m for the MV Karwela and P29 wrecks (depth ranges 39-42 m and 31-34 m, respectively), and 3 m x 3 m for the Um el Faroud wreck (depth range 27-31 m).

Ten photoquadrats of dimensions 30 cm x 30 cm were imaged within each hull's designated sampling area. Previous to sampling, grids representing the sampling area on each hull were generated digitally, with random photoquadrat positions assigned using a random number generator. In the field, divers used vertical and horizontal lines to locate the predetermined positions of the photoquadrats on the hulls. A PVC frame delineated the photoquadrats and maintained a fixed camera distance above each quadrat. Data collection was from August to October 2022. In the laboratory, Image J software [19] was employed to analyse images and quantify the area covered by variously coloured epibiota.

Organisms for later identification were collected by taking scrape samples from the wreck surfaces. Comparable assessments were carried out on three rocky surfaces as close as possible to each wreck site. The rocky surfaces were shallower than the wrecks (Table 1) as no rock was present at the depth of the scuttled vessels. Scrape samples of rock epibiota were procured from the same locations as the photoquadrats. In the laboratory, the collected organisms that also appeared in the photoquadrats were identified using published keys and manuals. Statistical analyses were carried out with R Studio [18].

Table 1 – Depth of natural rock surfaces sampled in the vicinity of each wreck site.

Site	Depth (m)
Um el Faroud	25
MV Karwela	32
P29	26

Results

Taxon richness (Table 2) and Simpson's diversity index (Table 3) were calculated for the hulls and neighbouring natural substrata.

For all wrecks, absolute taxon richness surpassed that of nearby rocky surfaces. Among the wrecks, MV Karwela exhibited the highest taxon richness, while Um el Faroud had the lowest. Simpson's diversity index was lower for the rocky substrata adjacent to the Um el Faroud and MV Karwela sites compared to the wrecks, indicating higher hull surface diversity. Notably, P29 was an exception, displaying lower diversity on the hull surface than the corresponding rocky substrate. The taxa recorded at each site are shown in Table 4.

Welch's two-sample t-test corroborated higher biodiversity on the Um el Faroud hull compared to the nearby natural surface ($p<0.05$). MV Karwela's hull presented a higher, and P29 a lower, Simpson's diversity index on the hull than on nearby natural surfaces, although statistical significance was not achieved (independent samples t-test, $p>0.05$).

Table 2 – Absolute taxon richness (total number of different taxa) on the wrecks' hulls and on nearby rocky surfaces.

Site	Hull	Rock
Um el Faroud	4	2
MV Karwela	7	2
P29	5	4

Table 3 – Mean Simpson's diversity index (± standard deviation) of the wrecks' hull and nearby rocky surfaces.

Site	Hull	Rock
Um el Faroud	0.55 ± 0.10	0.48 ± 0.02
MV Karwela	0.45 ± 0.09	0.38 ± 0.09
P29	0.43 ± 0.13	0.47 ± 0.04

Table 4 – Taxa collected form the hulls of the three wrecks and from adjacent natural hard substrata.

	Um el Faroud		MV Karwela		P29	
	Wreck Hull	Natural Substratum	Wreck Hull	Natural Substratum	Wreck Hull	Natural Substratum
Dasycladus vermicularis	x					
Gigartinales	x					
Ceramium sp.	x		x		x	
Turf	x	x	x	x	x	x
Cyanobacteria			x			
***Sphacelaria* sp.**			x			
Encrusting Coralline Algae			x			
Sporochnales			x			
Porifera			x		x	x
***Sargassum* sp.**					x	
***Cladophora* sp.**					x	
***Cystoseira* sp.**		x		x		x
***Titanoderma* sp.**				x		
Rhodymeniales				x		x
***Ulva* sp.**				x		

Functional group categorization (Encrusting, Turf, Filamentous, Short Arborescent, Tall Arborescent epibiota) was employed to explore succession on the wrecks (Figure 1). Turf and filamentous algae were ubiquitously present on the wrecks. Encrusting organisms were negligible on P29 and Um el Faroud, while the MV Karwela had a significant abundance of this functional group (Wilcoxon test, $p<0.05$) compared to the other wrecks. Turf cover showed no significant difference between wrecks (Kruskal Wallis test $p>0.05$), with MV Karwela having the highest value. Filamentous algal cover also showed no statistical difference between wrecks (Kruskal Wallis test, $p>0.05$). Short arborescent epibiota occurred solely on Um el Faroud, while tall arborescent algae were unique to P29, obviating statistical tests. Figure 1 also shows an evident difference between the cover area of the different functional groups on the wrecks and the respective nearby rocky surfaces. From Figure 1 it is also evident that the three rocky substrata had very similar cover of epibiont functional groups.

An NMDS ordination, based on functional group cover, was generated to evaluate similarity between wrecks (Figure 2).

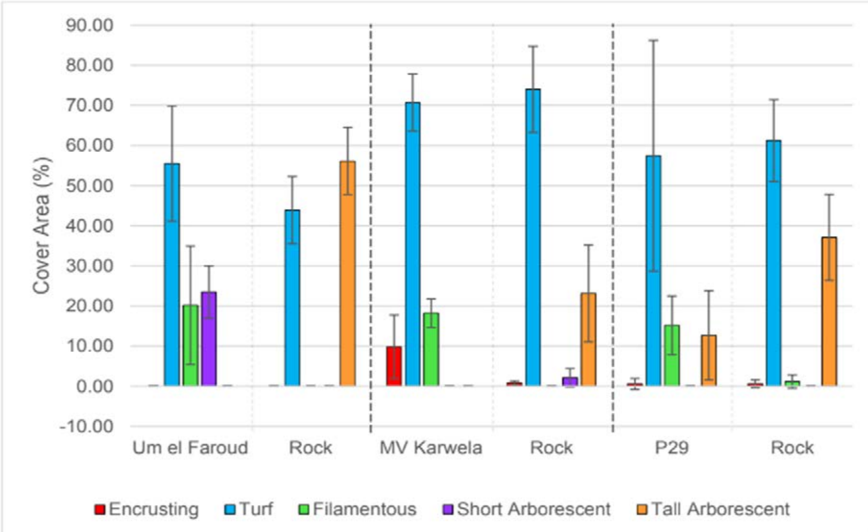

Figure 1 – Bar graph of Cover Area (%) of epibiont functional groups on the surface of the wrecks' hulls and nearby rocky surfaces. Error bars represent ±1 standard deviation.

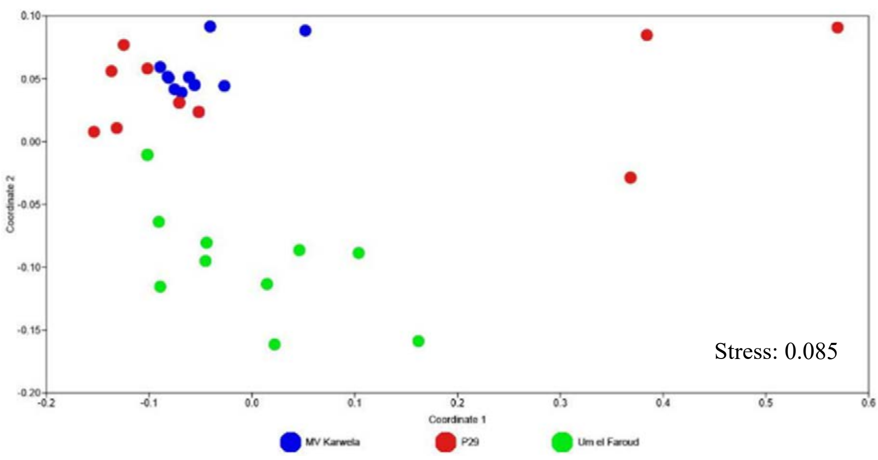

Figure 2 – Non-metric Multidimensional Scaling (NMDS) ordination diagram based on functional groups cover area (cm^2) in the photoquadrats sampled from the three wrecks.

Despite taxon differences, there is slight overlap in functional groups coverage between MV Karwela and P29. This implies greater taxonomic than functional group disparity among wrecks. While Um el Faroud does not overlap with the other wrecks, the photoquadrats samples for this wreck display a more dispersed distribution, indicating greater functional group variability compared to P29 and MV Karwela. Three photoquadrats, on the top right corner of the figure, are well separated from the rest. These three photoquadrats had a higher amount of bare surface area, a lower abundance of turf, and a slightly higher cover area of tall arborescent algae, compared to the other P29 photoquadrats. These three photoquadrats were collected from the lower region of the P29 hull sampling area, which may explain the observed distinctions [25]. Different parts of a wreck superstructure may be subject to different conditions and, as consequence, have different epibiotic assemblages.

Discussion

The observed pattern of colonisation by epibiota on wreck surfaces supports the hypothesis that the ecological succession on these surfaces reaches a specific stage but does not progress to a climax due to flaking off. Such a situation can be described as a "disclimax," resulting from the continuous disturbance caused by the conversion of metal surfaces into rust, leading to the shedding of old surfaces and the exposure of new metal substratum [11][17]. As a result, overall, the hull is characterised by a mosaic of bare patches and others with biota representing various stages of succession [9]. Bare surfaces were observed on all wrecks, consisting of rust on Um el Faroud and MV Karwela, and more extensive uncolonized areas, primarily painted surface, on P29. The presence of bare surfaces suggests frequent ecological succession interruptions and restarts.

Comparing the communities on the wreck hulls to nearby natural rocky surfaces provides supports the existence of a disclimax community and a dynamic situation rather than stability. Taxon richness on wrecks exceeded that on rocks, reflecting the mosaic of dissimilar assemblages in different stages of progression. Simpson's diversity index, reflecting the number and abundance of taxa, was significantly higher on Um el Faroud than the nearby natural surface, suggesting a developmental stage rather than a terminal assemblage. Functional group analysis revealed distinctions between wrecks and rocks, although turfs were dominant on both. Despite taxonomic dissimilarity, there was slight overlap in functional groups between MV Karwela and P29 as shown by the Non-metric Multidimensional Scaling analyses. However, Um el Faroud was clearly distinct from the other two wrecks, in terms of functional groups. Overall, there was a higher taxonomic dissimilarity than functional group dissimilarity among wrecks. These results suggest a truncated ecological succession on wreck surfaces, with each wreck exhibiting unique characteristics and developmental patterns.

Conclusions

The presence of uncolonized areas on wreck surfaces, even after prolonged immersion, demonstrates repeated surface sloughing and subsequent re-colonization. Mosaic colonization patterns were evident on all three wrecks, distinct from those on natural substrata, indicating a disclimax community system on each wreck. Variations in epibiotic functional group coverage between wrecks may result from geographic location, hydrodynamics, depth, and other factors, requiring further exploration. Notably, the Um el Faroud exhibited higher short arborescent epibiota cover, the MV Karwela featured greater encrusting epibiont presence, and only the

P29 hosted tall arborescent species. Succession on wrecks is a dynamic process and there is no long-term stability.

Acknowledgements

We would like to thank XDEEP for providing technical equipment, Orcatorch for supplying the illumination tools, and all the divers who participated in the data collection and without whom this study would not have been possible. We are grateful to an anonymous referee whose suggestions significantly improved an earlier version of this manuscript.

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TURTLETOSCA: DRONE MONITORING OF THE *CARETTA CARETTA* NESTS IN THE MIGLIARINO SAN ROSSORE MASSACIUCCOLI PARK

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Abstract: The loggerhead turtle (*Caretta caretta*) is the most abundant sea turtle species in the Mediterranean Sea. In 2023, 454 nests were identified along Italian beaches, these results represent the absolute Italian nesting record. It was also an exceptional year (2023) for Tuscany, in the central of Italy, where 24 nests were found. This area of central Italy seems to be no longer an exceptional site, so it is necessary to organize monitoring activities in order to cover most of the Tuscan beaches where *Caretta caretta* could nest. Between the mouths of two rivers, the Serchio and the Arno, lies a natural park, owned by the Tuscany Region, called the Migliarino San Rossore Massaciuccoli Natural Park (MSRM Park), a protected area with 34 km of protected coastline. With the aim of identifying, protecting and managing *Caretta caretta* turtle nests in this area, a monitoring program has been initiated using UAVs (Unmanned Aerial Vehicles), or drones, inside MSRM Park. In the first working season, which ran from June to August 2023, one carcass and some possible *Caretta caretta* tracks were identified, but no nest at the moment.

Keywords: Loggerhead Turtle, Unmanned Aerial Vehicle, Scientific Monitoring, Citizen Science

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Yuri Galletti, Alessandro Dini, Francesca Logli, Cecilia Mancusi, Silvia Merlino, Marco Paterni, Marco A. L. Zuffi, *TurtleTosca: drone monitoring of the* Caretta caretta *nests in the Migliarino San Rossore Massaciuccoli Park*, pp. 218-227, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.19

Introduction

The ranges of many species are shifting poleward as a result of global warming because environmental temperature is one of the major determinants of geographic distribution in animals. Being ectothermic, sea turtles are particularly sensitive to variation in environmental temperature, and they are expected to shift their range according to the movement of their climatic niche as an adaptive response to climate warming. The loggerhead turtle (*Caretta caretta*) is a priority species included in App. II/IV of the Habitats Directive whose conservation requires to activate a strict protection regime across the species' entire natural range, both within and outside Natura 2000 sites (Habitats Directive) and the identification of core areas (e.g. nesting beaches, foraging grounds, migratory corridors) that must be designed as Site of Community Importance and managed in accordance with the ecological requirements of the species. Located at the northern edge of the species range, the Mediterranean Sea has been colonized by individuals from the Atlantic population in at least two independent events in the late Pleistocene and the Holocene originating the current nesting populations in the central and eastern Mediterranean. The species has therefore survived past climatic changes by shifting its nesting range in accordance with the migration of its thermal niche. Yet the loggerheads' capacity to adapt to present and future climate changes is uncertain because of the accelerated rates of climate warming, cumulative impacts of human activities and restricted availability of alternative habitats caused by coastal urbanization. The successful colonization of new climatically suitable areas, in fact, does not only rely on the availability of environmental conditions favourable for embryonic development, but it is tightly linked to the exposure to threats on the nesting beaches deriving mostly from coastal development.

Nowadays the loggerhead turtle is the most abundant sea turtle species in the Mediterranean Sea. Italy hosts regular nesting events along the Ionic coasts of the southern Calabria and in the Pelagian Islands (Linosa and Lampedusa) [3], as well as along the southern Tyrrhenian Sea (Campania). In 2023, 454 nests were identified along Italian beaches, these results representing the absolute Italian nesting record. It was also an exceptional year (2023) for Tuscany, in the central of Italy, where 24 nests were found. In this region, the first nest identified dates back to 2013. Until 2018, only seven nests of the *Caretta caretta* species were documented in Tuscany. However, this area of central Italy seems to be no longer an exceptional site, so it is necessary to organize monitoring activities in order to cover most of the Tuscan beaches where *Caretta caretta* could nest.

In the Mediterranean area *Caretta caretta* is subject to a mix of anthropic pressures. Coastal development is associated with the permanent alteration of coastal habitats due to the presence of hotel resorts, tourism-related constructions such as restaurants, bars, houses and other businesses typically built along the beach. Light Pollution is one distinctive and particularly damaging form of habitat alteration caused by coastal development, defined as the introduction of artificially produced detrimental light into the environment. Hatchlings emerging from their nests at night depend upon subtle brightness cues to lead them safely to the sea. Bright artificial light sources attract hatchlings and lead them away from the ocean where the small turtles succumb to attacks by predators, exhaustion, desiccation, or strikes by vehicles on nearby roads and parking lots. Shore-based lights can also misdirect adult turtles, returning to the sea after nesting, in a similar way, wandering on the beach for hours. Recreational activities and beach management practices associated with coastal urbanization are also important threats. Driving on the beach and the use of heavy machinery for beach cleaning purposes are common practices and are responsible for alterations in sand characteristics, the destruction of turtle clutches and the deletion of tracks before sea turtle observers can record them.

Beach furniture, recreational equipment and other large objects left at night on the beach reduce the habitat available for nesting and prevent females from accessing suitable nesting sites. People on the beach during the night may disrupt nesting activity as females may abandon their nesting attempts or incubating nests may be destroyed through trampling or by umbrellas thrust into the sand. Moreover, recreational activities may result in an increase of nest predation risk from animals that are attracted to the beach due to the greater food availability.

Monitoring of nesting tracks is an essential first step for the management of the species and for correct use of the coastal strip. The involvement of volunteers is also important, encouraging the creation of citizen science projects in the environmental and ecological sciences. This work was born from a close collaboration between local authorities (the Municipality of Pisa and the Migliarino San Rossore and Massaciuccoli Natural Park), research institutions (CNR and the University of Pisa) and volunteer citizens. The activities also refer to the LIFE TURTLENEST project of which Legambiente NGO is the leader. Through a multi-disciplinary approach, the project will improve the conservation status of *Caretta caretta* aided by: i) the establishment of an international network; ii) the use of shared best-practice procedures specifically revised to mitigate the threats on emerging nesting sites; iii) the capacity building of trained field operators; iv) the identification of new index sites for monitoring; v) the strengthening of the Natura 2000 network. In conclusion, the goals of this project were: 1) to obtain the first information, through videos and images, of the presence of nesting traces of the *Caretta caretta* in the coastal stretch of the MSRM Park and 2) to increase the monitoring effort along the coastal strip of Tuscany, in an area not yet studied up to now.

Materials and Methods

Area sampling

Between the mouths of two rivers, the Serchio and the Arno, lies a natural park, called the Migliarino San Rossore Massaciuccoli Natural Park (MSRM Park), a protected area with 34 km of protected coastline.

The MSRM Park lies between 43° 51′ 36″ – 43° 35′ 25″ N and 10° 14′ 26″ – 10° 21′ 11″ E. It was established in 1979 in order to safeguard around 23 150 ha of dunes, mesophilous and xerophilous forests, wetlands and agro-forestry landscape, along approximately 30 km of coast. In 2004, UNESCO designated the park as a Biosphere Reserve. Although only constituting a fraction of the surface area of the park (about 394 ha, 1.7 % of the total area), the recent dune bands represent an area of extraordinary richness in terms of unique habitats and endemic plants. At the same time, however, there is strong anthropogenic pressure, linked to seaside tourism and the presence of urban settlements, and on some stretches significant erosion (GNRAC, 2006) [1]. In order to characterize the climate, temperature and precipitation data were used from a weather station located at the eastern edge of the park (San Piero a Grado, Pisa). Annual average rainfall for the ten-year period from 1997 to 2007 was 773 mm, with the highest rainfall recorded in the autumn, and an annual average temperature of 14.4 °C, with maximum values close to 30 °C. The area exhibits a period of summer drought and water shortages from June to September. The area has a Mediterranean macrobioclimate, with an upper meso-Mediterranean thermotype and a lower sub-humid ombrotype. The coastline of the park can be divided into three different sectors in relation to coastal dynamics and anthropization: i) the northern sector (N), about 8 km long is subject to protective restrictions but freely accessible to the public and with a low level of urbanization. The coastline is prograding (approximately 140 m since 1954). ii) The central sector (C), about 11 km long is subject to protective restrictions and closed to the public. The coastline is undergoing rapid erosion (approximately 180 m since 1954). iii) The southern sector (S), about 11 km long, is open to the public with partial protective restrictions [1].

Monitoring

During the nesting season (May–August), Legambiente and CNR staff and volunteers monitor sea turtle nesting tracks during morning patrols along the San Rossore beach in Pisa (Figure 1).

With the aim of identifying, protecting and managing *Caretta caretta* turtle nests in this area, a monitoring program has been initiated using UAVs (Unmanned Aerial Vehicles), or drones, inside MSRM Park, within the coastal stretch of protected area with access allowed, by the managing body, for research purposes only. Drones have made it possible to observe tens of kilometers of beach in the early hours of the morning. The work protocol applied envisaged the use of a Phantom 4 PRO v2 quadcopter-type UAV, which had already been used previously, in the same area, for environmental surveys of several types [2], [4], [5]. Inside this specific application, the drone performed an automatic flight over the coast profile up to a height of 30 m. Two operators performed the monitoring: the first performed the real-time observation on the UAV ground station monitor, the second performed the recorded observation on a high-resolution monitor from the UAV's SD memory, changed when replacing the battery. This allowed us a double reading and greater guarantee against errors of interpretation. The temporal frequency of the survey was twice a week, with the involvement of only two operators acting from two different access points.

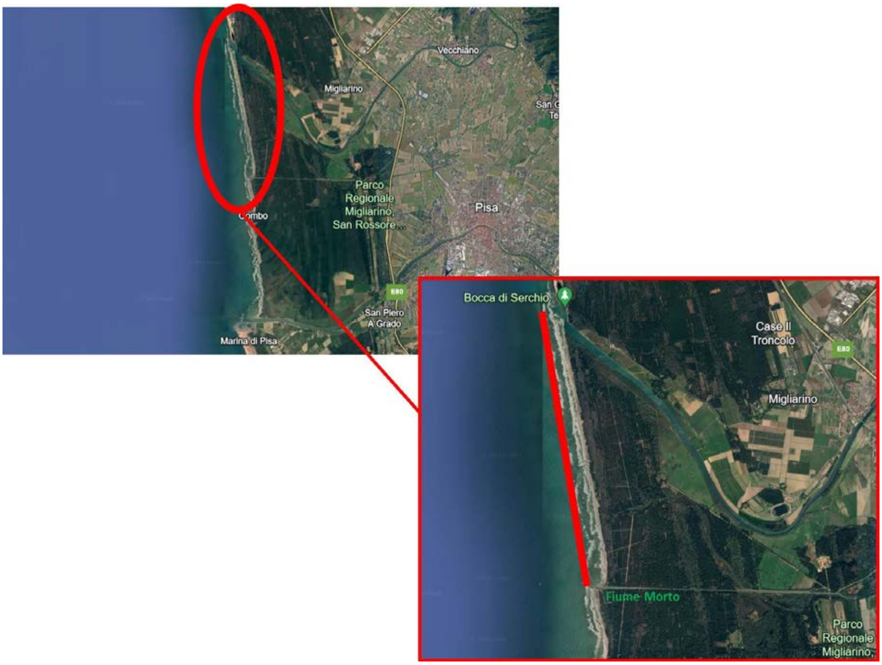

Figure 1 – The sampling area from Fiume Morto (south) to Bocca di Serchio (north).

Results

As part of this activity, 7.42 km were analyzed with a total flight time, excluding battery changes and movements, of 64 minutes at a height of 30 m. During the flight the camera aimed nadirally recorded the video in 4K format (4096×2160) with H264 CODEC. In the first working season, which ran from June to August 2023, one carcass and some possible *Caretta caretta* tracks were identified, but no nest recorded at the moment. The activities were carried out and disseminated, thanks to a citizen science project with the Legambiente NGO, which involved around 40 volunteers.

The first flights, 30 meters above the ground, made it possible to study the entire monitored beach in detail, identifying those possible sections obstructed by the presence of wood or by an excessive quantity of accumulated beach litter.

We point out two images taken by the drone which represent an area with human footprints (Figure 2), in an area where it is possible to access only with authorization of MSRM Park and a second figure, where a "U" shaped structure can be seen (Figure 3). In this case an inspection had to be carried out to better investigate the footprint. These were two furrows left by the movement of some trunks.

Figure 2 – Human footprints on the sand.

Figure 3 – “U” shaped on the sand.

Another image instead led to the discovery of a sea turtle carcass (Figure 4). The image at thirty meters above sea level was already very clear, however an inspection was subsequently carried out to observe the state of decomposition of the animal (Figure 5).

Figure 4 – *Caretta caretta* carcass from above.

Figure 5 – *Caretta caretta* carcass inspection.

The last image shows a possible nesting attempt of the marine reptile in search of a suitable place for nesting (Figure 6). After that, more in-depth research, carried out by expert technicians, ruled out that the track in Figure 6 had been left by a female of Loggerhead sea turtle.

Figure 6 – False nesting attempt.

Discussion

This activity was the starting point for a new project of scientific monitoring of the coast of a protected natural area. Furthermore, it was also a citizen science project, with the organization of training activities aimed at new volunteers.

In general, one of the possible reasons for the absence of nesting within the protected area of the park could be the presence of considerable quantities of material, much of it anthropogenic, accumulated on these beaches, due to the presence of the nearby river outlet of the Arno and the lack of frequent beach cleaning operations. This considerable amount of material could act as a deterrent for spawning, although further investigation will be necessary to confirm this hypothesis. In any case, the protocol developed, based on the aerial survey, has proven to be extremely efficient, allowing for frequent surveys even in areas with difficult direct access to the sites to be examined, limiting anthropogenic impact in protected and fragile environments, and greatly reducing the number of personnel required for this type of investigation.

The discovery of the carcass from above made possible the subsequent intervention in the field and the activation of the procedure for the recovery of the animal.

It should be highlighted that nesting attempts must always be verified, to understand if they are real and, possibly, investigating why the nesting was not successful.

This result showed the effectiveness of the tool in searching for any carcasses of marine animals, suggesting that the identification of these in protected natural areas, remote or difficult to access areas could be facilitated by the use of these tools. The tool can be so useful in a coastal protected natural area to study other critical issues of the territory, such as coastal erosion or even the invasion of alien species.

For the future, the presence of possible traces is a first step towards identifying the nest, the next phase must be that of recognition in the field.

Conclusions

It is extremely important for the conservation and protection of the species to understand if nesting sites considered occasional could become regular nesting areas over time.

Shots from above make it possible to identify the tracks of the turtles that come out of the sea in search of the possible right point in which to dig their nest in the sand. In addition the images from UAVs can provide valuable information about the environment, including changes in land cover, vegetation health, and even wildlife behavior.

In conclusion it should be stressed that protecting the species also means dealing with environmental, social and economic questions. Climate change and global warming impact biodiversity and ecosystems and, consequently, our territories and our lifestyle. Taking care of the protection of the Loggerhead sea turtle also means safeguarding the economies of our territory. *Caretta caretta* contribute indeed to local economies through ecotourism, particularly in areas where turtle watching is a popular activity. They also play a vital role in marine ecosystems, affecting the population dynamics of jellyfish and other species.

Acknowledgments

We thank the volunteers from Legambiente who participated in the monitoring surveys. A special thanks to Stefano di Marco, Legambiente, and Lorenzo Bani, president of MSRM Park, for their collaboration throughout the project.

Author Contributions

YG conception and design of the study, methodology and training of citizen scientists, investigation, formal analysis, writing - original draft, review, and editing. SM and MP methodology, investigation, formal analysis, writing - original draft, review, and editing. CM and MZ methodology and training of citizen scientists, investigation, formal analysis, writing - original draft, review, and editing. AD training of citizen scientists, investigation, writing – review and editing. FL writing – review and editing.

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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MONITORING AND ASSESSMENT OF THE ECOLOGICAL STATUS OF CORALLIGENOUS CLIFFS BY A STANDARDIZED PROTOCOL

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Abstract: Coralligenous reefs are the main biogenic construction of the Mediterranean Sea and one of the most sensitive habitats for which European legislation requires monitoring and quality assessment plans. The heterogeneity of reefs however requires the use of standardized habitat-specific methods allowing comparability of data over wide scale. Coralligenous cliffs are the reef type most widespread in shallow waters and are monitored by several ecological indices based on different approaches. This contribution summarizes the results of multi-year studies carried out on wide spatial scale with the aim of comparing and integrating the different methods into a single standardized sampling and data collection protocol. Downstream of a literature review, the STAndaRdized coralligenous evaluation procedure (STAR) was proposed and tested on subregion scale under different human pressures. Results confirmed the validity of descriptors chosen and the effectiveness of the protocol in assessing the ecological quality of coralligenous cliffs. STAR represents the first methodological guidelines proposed for the evaluation of the ecological quality of coralligenous cliffs in the Mediterranean Sea

Keywords: biogenic construction, ecological quality, evaluation, guidelines, Mediterranean Sea

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Referee List (DOI 10.36253/fup_referee_list)
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Paola Gennaro, Luigi Piazzi, Enrico Cecchi, Carla Morri, Carlo Nike Bianchi, Monica Montefalcone, *Monitoring and assessment of the ecological status of coralligenous cliffs by a standardized protocol*, pp. 228-239, DOI: 10.36253/979-12-215-0556-6.20

Introduction

Coralligenous reefs represent the most important circalittoral bioconstruction in the Mediterranean Sea for extent, biodiversity, and carbon dynamics [3,4]. They are an iconic underwater seascape providing multifarious ecosystem services, but they are also a very sensitive habitat vulnerable to both global and local disturbances; thus, coralligenous reefs are included in the European Red List of Habitats and their monitoring and quality assessment are required under European Directives and international treaties. The heterogeneity of the coralligenous habitat makes it difficult to identify unequivocal threats, study methods and ecological indicators [17], so the development of habitat-specific plans for monitoring and assessment based on standardized methods are strongly required, in order to allow data comparability over a wide space and time scale. Among different reef morphologies, the coralligenous cliff is the most widespread in the first 40 m depth, and the most exposed to the effects of climate change and anthropogenic pressures affecting coastal waters [19]. It is hence considered a sensitive bioindicator, as well as a habitat under high risk of degradation, for which many ecological indices were developed in the last decade to evaluate its health status [7]. However, these indices are based on different approaches and metrics which, in the absence of an integration/intercalibration process, could prevent the comparison of results obtained with different methods in different areas of the Mediterranean Sea; this may lead to greater difficulties in the application of shared intervention measures for the maintenance and restoration of good environmental status as required by European directives. This contribution summarizes the results of multi-year studies carried out through underwater surveys on a large spatial scale, aiming at comparing and integrating methods used at the Mediterranean level in a standardized single protocol for sampling and data collection.

Materials and Methods

The relevant literature on coralligenous reefs in the Mediterranean Sea was searched, together with the proceedings of the main Mediterranean workshops and other specialized symposia. Among the 95 scientific papers dealing with shallow coralligenous reefs, 52 studies reporting detailed information about sampling methods applied to assess the ecological quality of coralligenous cliffs were selected. Methods applied by different authors were compared to identify the best sampling strategy and to select the ecological descriptors common to most indices and most sensitive to human pressures. The information collected was synthesized in a STAndaRdized coralligenous evaluation procedure (STAR) performed by SCUBA divers, following a non-destructive protocol which allows obtaining information about most of descriptors used by different indices through a single sampling effort and data analysis [8,15].

The new procedure was first tested in 8 locations of the Italian coast [15] and then applied across the Western Mediterranean subregion for a total of 48 locations and 95 sites of coralligenous cliffs investigated to date along the Italian and French coasts (Fig. 1). To test the protocol on a large scale, 30 locations subject to different human pressures were selected along the Italian coasts. The level of human pressures was defined according to the anthropization index, which considered the nine main impact factors affecting coralligenous reefs (urbanization and urban waste, ports, tourism, industrial activities, sediment load, aquaculture, agricultural waste, fishing and anchoring) which were assigned a score from 0 (no impact) to 2 (strong impact) based on the presence and extent of the human pressure and distance of the sites from the source of impact [16].

For each site, the anthropization index, ranging from 0 to 13, was calculated as the sum of the values of each individual impact factor. Three plots of area 4 m^2, tens of metres apart, were sampled at each site on vertical bottoms at about 35 m of depth and 10 photographic samples of 0.2 m^2 were collected for each plot. The thickness of the calcareous layer was measured through a hand-held penetrometer (six replicated measures per each plot) and each measurement was assigned to a thickness class as follows: 1 for null penetration, as in the absence of biogenic substrate, 2 for a centimetric penetration, indicating a not yet consolidated bioconstruction, and 3 for a millimetric penetration, which occurs in the presence of active bioconstruction resulting in a calcareous biogenic layer [9].

The maximum height of the erect species was measured *in situ* and the percentage of necrosis/epibiosis of the erect anthozoans was assessed through a visual approach taking account the following percentage cover classes: 1 for $N > 75$ %, 2 for $10\% \leq N \leq 75$ % and 3 for $N < 10$ %. Photographic samples were analysed by the ImageJ software [18] to evaluate the presence and percentage cover of the main taxa or morphological groups and the sediment deposit [6]. A value of Sensitivity Level (SL) has been assigned to each taxon/morphological group, with values varying within a numerical scale, from the lowest ones corresponding to the most tolerant organisms to the highest values for the most sensitive ones [16,8]. To calculate the SL of study sites, each taxon was associated with a sensitivity value and with one of eight classes of abundance (1: $0 < \% < 0.01$; 2: $0.01 < \% < 0.1$; 3: $0.1 < \% < 1$; 4: $1 < \% < 5$; 5: $5 < \% < 25$; 6: $25 < \% < 50$; 7: $50 < \% < 75$; 8: $75 < \% < 100$) according to [15]. The SL of each photographic sample was calculated as the sum of the values obtained by multiplying the sensitivity value of each taxon/group by its class of abundance and the SL of each study site was calculated by adding the SL values of all samples. The α-diversity was calculated as the mean number of taxa/morphological groups per photographic sample, and the β-diversity was calculated as heterogeneity of assemblages expressed as distance from centroids measured in a multivariate dispersion through PERMDISP analysis [1].

The data collected with the STAR protocol were used to calculate the ESCA (Ecological Status of Coralligenous Assemblages) [16] and COARSE (COralligenous Assessment by Reef Scape Estimate) [9] indices, in order to evaluate the ecological status of coralligenous cliffs through a biocenotic and seascape approach respectively. ESCA was expressed as Ecological Quality Ratio (EQR'), calculated as the mean of the EQRs obtained for the biocenotic descriptors compared to reference conditions [6], and its values provide the following ecological quality status classification: i) high ($EQR \geq 0.8$); ii) good ($0.6 \leq EQR < 0.8$); iii) moderate ($0.4 \leq EQR < 0.6$); iv), poor ($0.2 \leq EQR < 0.4$); and v) bad ($EQR < 0.2$) [16]. The COARSE index was expressed as Quality value for each site (Q'), calculated as the mean of the Qs obtained for the three layers characterizing coralligenous reefs (basal, intermediate and upper layer) [9], and classified as follows: i) high (2.55<Q'≤3); ii) good (2.35<Q'≤2.55); iii) moderate (2.05<Q'≤2.35); iv), poor (1.55<Q'≤2.05); and v) bad (Q'≤1.55). A linear regression was performed in order to test the response to human pressures of descriptors selected and of the ESCA and COARSE ecological indices. The degree of correlation was expressed as value of the square correlation coefficient (determination coefficient, R^2) and significance of regression was tested by means of the Fisher-Snedecor test performed by the Statistica 10 software.

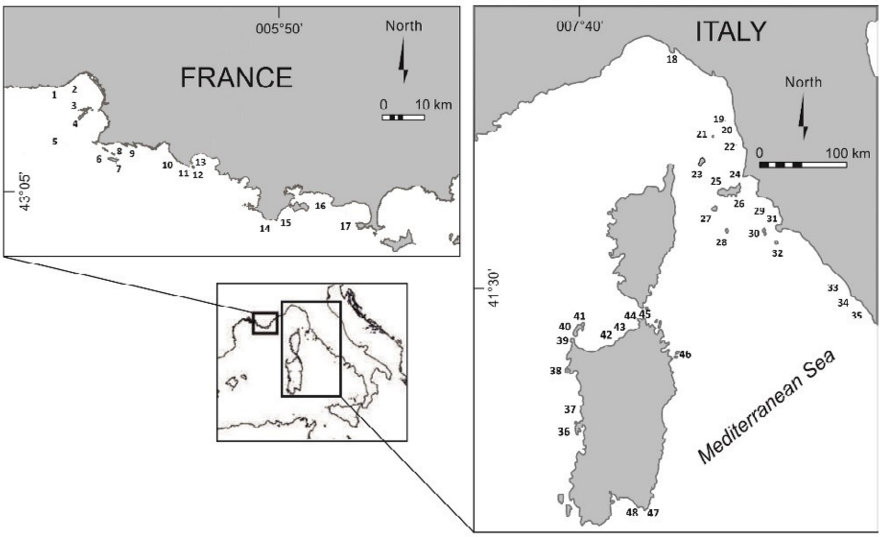


Figure 1 – Map of the 48 locations investigated: Méjean (1), Large Niolon (2), Tiboulen du Frioul (3), Ile du Planier (4), Cap Caveau (5), Moyade (6), Ile Plane (7), Impérial Milieu (8), Morgiou (9), Figuerolle (10), Bec de l'Aigle (11), Les Rosiers (12), Pierre du Levant (13), Sêche des Pêcheurs (14), Les Deux Frères (15), Large Oursinière (16), Formigue (17), Portofino (18), Meloria (19), Livorno (20), Gorgona (21), Vada (22), Capraia (23), Piombino (24), Elba N (25), Elba S (26), Pianosa (27), Montecristo (28), Formiche di Grosseto (29), Giglio (30), Argentario (31), Giannutri (32), Sant'Agostino (33), Santa Marinella (34), Civitavecchia (35), Catalano (36), Bosa (37), Capo Caccia (38), Stintino (39), Asinara S (40), Asinara N (41), Castel Sardo (42), Costa Paradiso (43), Capo Testa (44), Santa Teresa (45), Tavolara (46), Torre Stelle (47), Capo Carbonara (48).

Results

The regression model performed for the ecological descriptors selected always showed a significant negative correlation between values of the anthropization index and those of SL ($F < 0.001$), α-diversity ($F < 0.001$), β-diversity ($F < 0.001$), thickness of the calcareous matrix ($F < 0.01$) and necrosis/epibiosis ($F < 0.001$), while a significant positive relationship was highlighted for the turf/sediment descriptor ($F < 0.001$) (Fig. 2 a, b). A significant negative correlation was also highlighted for both the ESCA ($F < 0.001$) and COARSE ($F < 0.001$) relationship with the anthropization index (Fig. 3). Values of the ESCA index ranged between 0.98 and 0.45 and most of the locations investigated were in high and good ecological status, while six of these were in moderate ecological status (Fig. 4a).

The COARSE index showed a higher variability of the classification values, with locations ranging from high to bad ecological quality status (Fig. 4b).

Discussion

The results confirmed the validity of the descriptors chosen and the effectiveness of the STAR approach in assessing the ecological quality of coralligenous cliffs. Sediment deposition is one of the main physical alterations affecting coastal areas and coralligenous cliffs are particularly vulnerable to this kind of disturbance, as increasing sedimentation may affect assemblages by covering sessile organisms, clogging their filtering apparatus and inhibiting the rates of recruitment, growth and metabolic processes [2]. Many correlative and experimental studies highlighted severe shifts in the structure of coralligenous assemblages subjected to several kinds of stressors; thus, the species sensitivity to environmental alterations can be a valid descriptor of the environmental quality of the habitat [11]. Moreover, both the richness and the heterogeneity of the assemblages decrease under stressed conditions [2]. In fact, coralligenous assemblages are usually characterized by a high variability at small spatial scale and consequently by high values of β-diversity, which is related to the heterogeneity of the substrate and competition for space [3]; under stressed conditions, the loss of structuring perennial species and proliferation of ephemeral algae lead to a widespread biotic homogenization, with consequent loss of β-diversity [2].

Bioconstruction by coralline algae is considered highly vulnerable to most effects of climate change, such as global warming and ocean acidification, but also to other environmental alterations, such as mucilage blooms, increasing sedimentation and mechanical damages by anchoring and fishing [3]; therefore, structure and health of coralline algae represent a primary descriptor of the ecological status of coralligenous cliffs.

Erect anthozoans are long-living organisms which are considered key species of coralligenous cliffs; they are affected by physical and climatic factors and by several human activities acting locally, such as fishing, anchoring or scuba diving [10]. Thus, although the presence and abundance of erect anthozoans may be independent of the environmental quality and related to natural factors, where they are present they can be usefully used as ecological indicators through the measure of different variables, such as the cover of colonies and the occurrence of necrosis and epibiosis [9]. The selected descriptors proved to be effective indicators of anthropogenic disturbance and the application of the STAR protocol made it possible to collect and integrate into a common database, and through a single sampling effort, the information they conveyed for the calculation of different ecological indices developed up to date, even with different approaches.

The ESCA and COARSE indices, in fact, are based respectively on a biocenotic and seascape approach, and can be considered a particular case of application of the STAR method to the analysis of data coming from the field database. The two indices proved to be effective in classifying the quality status of the assemblages investigated, albeit with some discrepancies consistent with the two different approaches. In particular, ESCA, using biocenotic descriptors, provide information on the alterations affecting different aspects of biodiversity at different levels of biological organization. COARSE focuses on the coralligenous stratocenoses, providing information on different pressures affecting different layers in the investigated area; consequently, assemblages naturally devoid of erect layer may be penalized by the integration of the three stratocenoses.

Different indices can use different metrics, thus providing complementary information on the effects of different anthropogenic pressures; for this reason, the use of a standardized sampling protocol to collect information from different descriptors and ecological levels is fundamental for the effectiveness of the large scale monitoring plans, as the simultaneous use of different ecological indices allows for a more complete assessment of coralligenous ecological status in relation to both anthropogenic pressures and variability of assemblages [8].

STAR is a non-destructive, simple but effective protocol that combines the photographic approach with the *in situ* visual measurement, optimizing the balance between sampling effort and information obtained, in respect of the habitat investigated. This is particularly important in the context of monitoring protected habitats, where destructive techniques should be avoided.

Destructive methods are usually considered the most effective in evaluating some important ecological parameters, like species composition and diversity of assemblages [12,13], but they are also impactful and expensive in terms of analysis time and expertise required [14]. Anyway, the significant response of descriptors tested versus anthropogenic pressures confirmed previous studies on the negligibility of the information lost with the photographic approach [14]. Moreover, the information obtained from a mixed approach integrating photographic and visual sampling techniques was more complete than that provided by individual approaches, allowing to reduce the time and costs associated with data collection, which in fact represents the most expensive part of the monitoring plans [8].

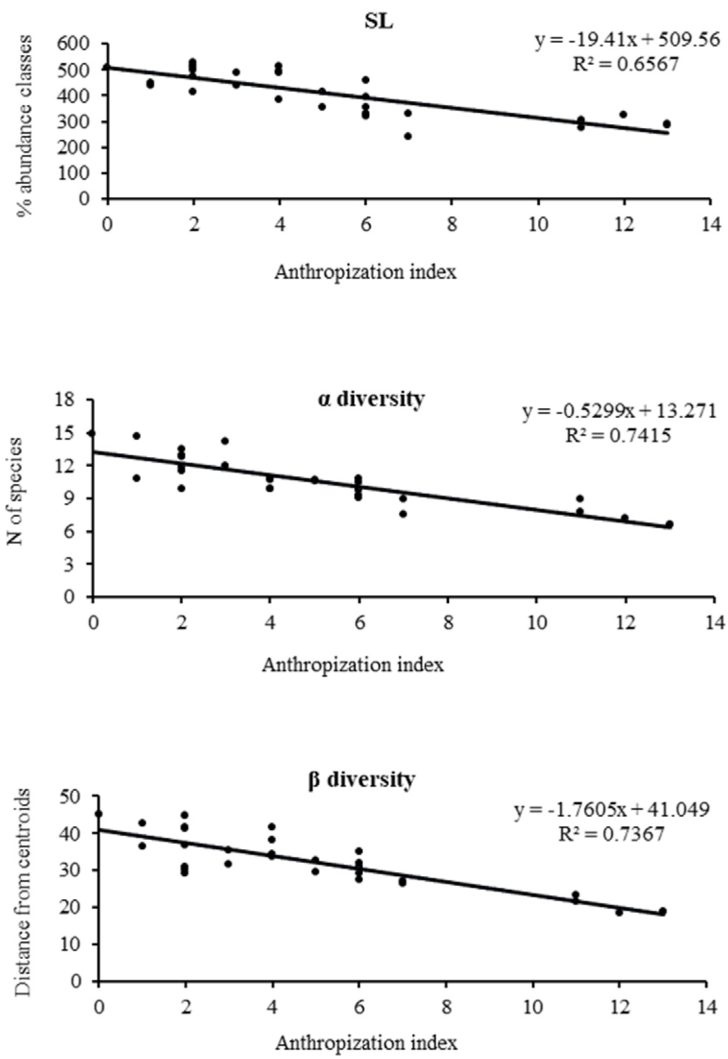


Figure 2a – Regression between the biocenotic descriptors and the anthropization index.

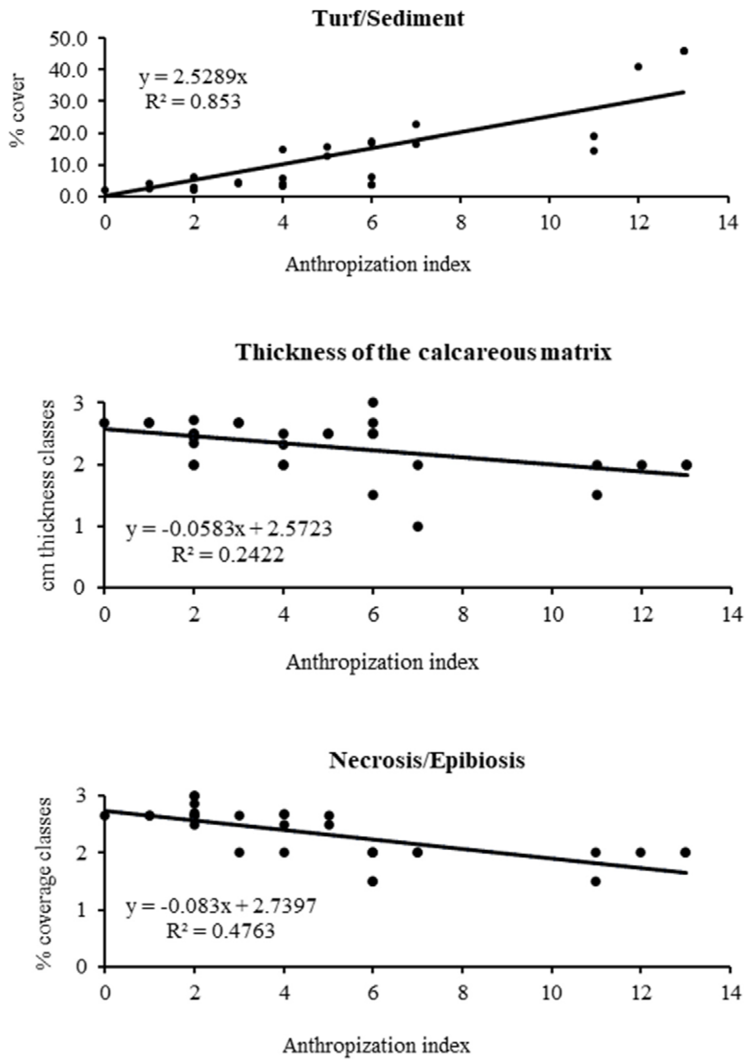
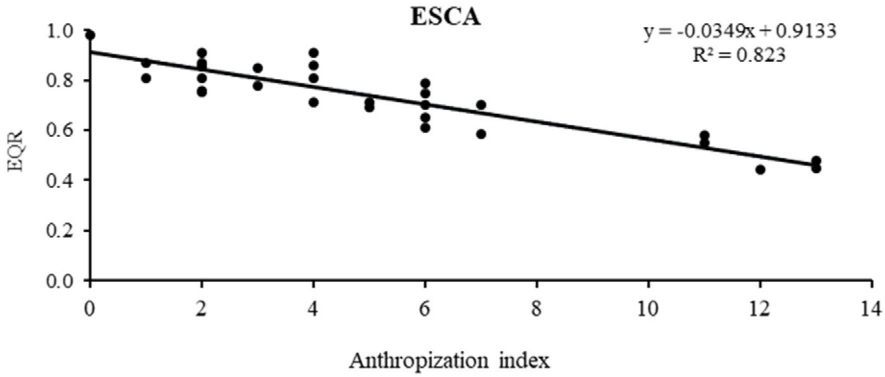


Figure 2b – Regression between the physical and biological descriptors and the anthropization index.



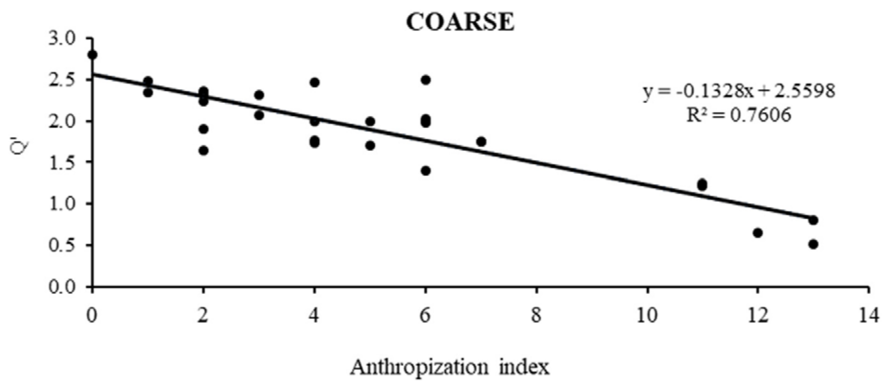


Figure 3 – Regression between values of the applied indices and the anthropization index.

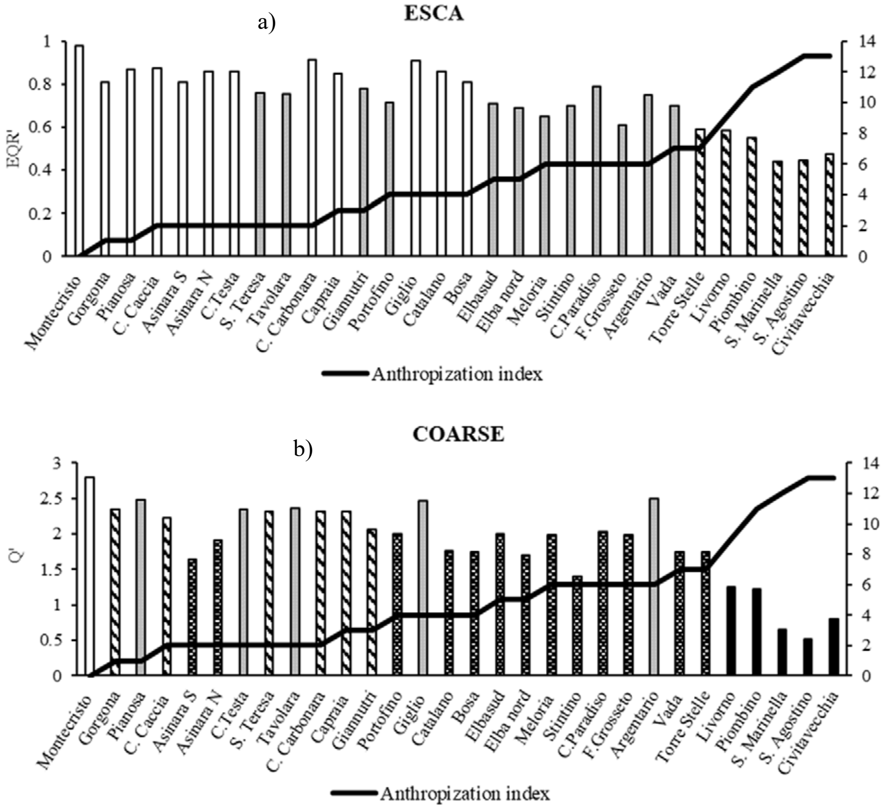


Figure 4 – Values of the anthropization index (black line) and the ESCA (a) and COARSE (b) indices (bars) in each of the 30 locations. White bars correspond to a high ecological quality, grey bars to a good one, the striped ones to moderate ecological quality, dotted bars to a poor ecological quality and black bars to bad ecological quality status of the coralligenous cliffs.

Conclusions

The European legislation recalls the need to develop standardized monitoring protocols for the acquisition of data and application of ecological quality indices, with the aim of promoting the intercalibration processes of methods and providing a common reference framework for comparison of the coralligenous ecological status among different areas of the Mediterranean Sea [8]. In this framework, the development of monitoring methods that take into account the heterogeneity of coralligenous habitat is recommended [20]. The STAR protocol aims at standardizing data collection on a particular type of coralligenous growing on vertical walls within 40 m of depth. This in order to monitor the health of the coralligenous habitat most widespread in surface waters and most sensitive to human disturbance, while responding to the need to separate the shallower habitats from the deeper ones. The STAR protocol was tested in the Western Mediterranean and it successfully integrated and standardized the monitoring methods for assessing ecological quality of shallow coralligenous reefs, thus favouring the development of an effective network for their conservation. In fact, the use of a standardized procedure may allow for the comparison among the information provided by different ecological indices applied throughout the Mediterranean Sea, favouring the intercalibration of the ecological quality values obtained on a large scale. The use of multiple descriptors and the integration of information from multiple ecological levels is the proper approach to identify change in ecosystem quality [5]; moreover, the simultaneous use of different ecological indicators allows for the detection of community responses to specific pressures, for better addressing the intervention measures and conservation plans under European legislation. In this framework, STAR represents the first methodological guideline proposed in the Mediterranean as a tool for environmental policies concerning protection of coralligenous habitats [8] and may constitute a milestone for the development of increasingly accurate and effective tools shared on a broader Mediterranean scale.

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DEVELOPMENT OF A FRAMEWORK FOR MODELLING STAND EVAPOTRANSPIRATION AT A LOCAL SCALE IN A COASTAL MEDITERRANEAN FOREST UNDER CLIMATE CHANGE

Danilo Lombardi, Kristina Micalizzi, Marcello Vitale

Abstract: This work presents a novel approach for local-scale quantification of stand plant transpiration. The methodology integrates leaf-scale gas exchange, meteorological, and soil water content data with satellite data to upscale results to the stand-scale. Field data enables the calibration of a photosynthesis biochemical model, comprising three modules simulating species-specific net assimilation rates, stomatal conductance, and evapotranspiration rates (ET). ET values, calculated per species, calibrate a forest stand evapotranspiration (ETA) model based on NDVI. ET and ETA, along with other forest system fluxes, compute the forest water balance as soil water content (SWC). Both models effectively simulate SWC ($R^2_{species} = 0.98$, $R^2_{satellite} = 0.96$). Transpiration values and other water balance components are estimated using climate change scenarios (SSP 2.6 and SSP 8.5). Simulated stand evapotranspiration for 2022 is 1387.73 mm, while for SSP 2.6 and SSP 8.5 are 1216.49 mm and 1293.47 mm, respectively.

Keywords: Mediterranean ecosystem, ecological modelling, evapotranspiration, forest water balance, climate change.

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Introduction

This work introduces the critical role of evapotranspiration (ET) in ecosystem water cycling, particularly in arid and semi-arid Mediterranean environments. ET includes evaporation from soil and plant transpiration, and it is influenced by climate, water availability, and vegetation [21]. It significantly impacts the land-surface water and energy budget [18], and influences aquifer recharge in the Mediterranean region [6, 13, 20]. Estimating ET is challenging due to the heterogeneity in physical and physiological properties underlying plant water uptake and ecosystem water use [23, 27]. Various methods, including field observations and modelling approaches [7, 30], have been developed to quantify stand-scale transpiration [36]. However, the reliability of these models is constrained by appropriate parameterization and identification of dominant factors affecting forest transpiration [35]. Hydrological constraints have driven genetic and morphological adaptations within Mediterranean flora [32]. Predictions indicate that Mediterranean regions will experience severe or extended periods of drought, potentially causing shifts in species composition and forest coverage [33]. These alterations could promote drought-tolerant functional strategies [15], influencing environmental services rendered by forests, particularly those associated with the hydrological cycle. Evaluating ET across natural vegetation within the Mediterranean region is crucial for monitoring water stress and formulating sustainable restoration management policies [3, 4]. This study provides a replicable methodology for any ecological context, particularly those of reduced extensions, facilitating the development of strategies for monitoring and managing small forest areas. Local scale studies are essential for expanding our understanding of the relationships between vegetation composition, climate, ET, and water balance [21].

Materials and methods

Study area

The study was conducted in the "Bosco di Palo Laziale", located in the territory of Ladispoli (Rome, Lazio Region). This is a forested area of approximately 50 hectares, situated 230 meters from the sea, with an altitude ranging between 3 and 10 meters above sea level. It is a very dense Mediterranean forest composed of a declining oak grove and a high maquis. Between 2000 and 2003, about four thousand individuals (about 20 hectares), mainly of the Quercus genus, died due to stress from intense summer aridity and the spread of the fungus *Biscougnaxia mediterranea* [29]. According to the bioclimatic characteristics of the area, the site is characterized by a Mediterranean climate with precipitation concentrated in winter and autumn and aridity during the summer. The soil is of the clay-loam type composed of 45 % silt, 34 % clay and 21 % sand.

Climatic data

In situ climatic data were provided by the meteorological station "LADISPOLI - Palo Laziale", part of the monitoring network managed by the Integrated

Agrometeorological Service of the Lazio Region (SIARL) (https://www.siarl-lazio.it/). Climatic parameters recorded by the meteorological station are average daily temperature (T_{avg}, °C), maximum and minimum daily temperature (T_{max}, T_{min}, °C), average daytime and nighttime temperature (T_{day}, T_{night}, °C), daily rainfall (Prec, mmd^{-1}), daily potential evapotranspiration (Et_0, mmd^{-1}), daily relative humidity (RH, %), daily total and photosynthetically active radiation (RAD, PAR, MJm^{-2}) and atmospheric pressure (P_{atm}, hPa).

Gas exchange measurements

Gas exchange measurements and micrometeorological data were recorded using a portable infrared gas exchange analyser, Ciras-2 (Portable Photosynthesis System, © 2010 PP Systems) (https://ppsystems.com/). Main ecophysiological parameters measured by Ciras-2 were leaf temperature (Tl, °C), stomatal conductance (gs, $mmolH_2Om^{-2}s^{-1}$), transpiration rate (Et, $mmolH_2Om^{-2}s^{-1}$), and net photosynthesis rate (An, $\mu molCO_2m^{-2}s^{-1}$).

The measurements were carried out between March and October 2022 from 9 a.m. to 4 p.m. on the following species: *Phillyrea latifolia*, *Pistacia lentiscus*, *Quercus cerris* and *Fraxinus angustifolia sub. oxycarpa*, which together make up more than 70 % of the forest composition.

The sampling method includes "spot" measurements (single instantaneous measurements of the physiological parameters under environmental conditions) and the construction of photosynthesis response curves to CO_2 (from 400 ppm to 1000 ppm) at saturating PAR (1000 $\mu mol\ m^{-2}\ s^{-1}$) and constant temperature (25 °C), pressure (1020 mbar) and relative humidity (60 %).

Satellite data

The NDVI (Normalized Difference Vegetation Index) values were obtained from satellite imagery collections provided by the SENTINEL-2 mission. NDVI values with a resolution of 10 m/pixel were calculated, in Google Earth Engine environment (GEE, https://earthengine.google.com/), as the normalized difference of the near-infrared (NIR, 835.1÷833 nm) and red bands (Red, 664.5÷665 nm) (eq.1):

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{Red})}{(\mathrm{NIR} + \mathrm{Red})} \qquad 1$$

All available images for the period from January 2022 to December 2022 were used to extract the NDVI values. The images were processed to obtain a raster containing the median NDVI values per pixel for each month.

Framework: Bottom-Up and Top-Down Approach

The workflow involves integrating leaf-scale gas exchange measurements, meteorological and soil water content ground data (bottom-up approach) with satellite-derived data to up-scale results to stand-scale (top-down approach).

The field measurements allowed the calibration of a biochemical model of photosynthesis based on Farquhar and Von Cammer's ones [34], consisting of three interconnected modules designed to simulate net assimilation rates, stomatal conductance and transpiration rates. The species-specific stomatal control strategies were integrated in the model through the application of a constraint grounded in the theory of marginal carbon cost of water use [25]. According to this approach, optimal stomatal behaviour is achieved by maximizing carbon gain while minimizing water loss within a specific timeframe.

The species-specific ET values obtained from the biochemical model were used to calibrate the NDVI-based forest stand evapotranspiration (ETA) model [24].

The values of ET (evapotranspiration obtained from the biochemical model) and ETA (satellite-derived evapotranspiration) were alternately entered into equation 5, which allowed the quantification of soil water content. The accuracy of the output was assessed by comparing the simulated values with daily measured SWC data obtained from three soil probes placed at 30 cm of depth within the study area.

Subsequently, transpiration values (ET and ETA) and others water balance components were estimated by using precipitation and temperatures from the climate change scenarios (SSP 2.6 and SSP 8.5) as climate inputs.

Bottom-Up approach: Evapotranspiration leaf scale modelling

The species-specific stomatal conductance gs is obtained by eq.2:

$$gs(t) = g_0 + 1.6\left(1 + \frac{(g_1 * fw)}{\sqrt{VPD}}\right)\frac{An(t)}{Cs} \qquad 2$$

where VPD is the vapour pressure deficit, Cs is the atmospheric CO_2 concentration (410 ppm), An(t) is the net photosynthesis rates calculated using de Wit's [10], g0 ($molH_2Om^{-2}s^{-1}$) represents the residual stomatal conductance when the net assimilation rate reaches zero, while g1 ($Kpa^{0.5}$) is the sensitivity of the conductance to the assimilation rate [9, 25]. The values of g0 and g1 for each species are reported in the Table 1. The parameter fw applied to equation 2 represents the soil water stress factor as a function of the soil water content SWC ($m^3_{H_2O}m^{-3}_{soil}$), the wilting point Wp (0.194 $m^3_{H_2O}m^{-3}_{soil}$) and the field capacity Fc (0.322 $m^3_{H_2O}m^{-3}_{soil}$) [22].

Table 1 – Values of g_0 and g_1 for target species [22].

	Q. cerris	*F. angustifolia*	*P. latifolia*	*P. lentiscus*
g_0	0.030	0.019	0.046	0.018
g_1	2.06	1.91	2.12	2.06

The annual canopy transpiration ET (mmH_2Oy^{-1}) is calculated by integration over time of the instantaneous Et(t) (eq.3):

$$ET = \sum_{1}^{365} \frac{(\lambda * gs(t) * (VPD/Patm))}{\lambda} * 3600 * photoperiod \quad 3$$

where λ is the latent heat of water vaporization (kJ mol^{-1}).

Top-Down approach: Evapotranspiration Forest scale modelling

For the computation of evapotranspiration (ETA, mmH_2Od^{-1}) from satellite data, the NDVI-CWS model [2, 24] has been modified by substituting the water stress factor (CWS) with fw (eq.2) [22].

ETA is given by eq.4:

$$ETA = Et_0 * \left[FVC * Kc_{Veg} + (1 - FVC) * Kc_{Soil}\right] * fw \quad 4$$

where Et_0 represents the potential evapotranspiration directly measured from the climate station, FVC denotes the fraction of vegetation cover, indicating the amount of leaf biomass transpiring in the pixel, obtained from the NDVI, 1-FVC corresponds to the portion of bare soil in the pixel subject to evaporation, Kc_{veg} and Kc_{soil} represent the vegetation and soil transpiration coefficients, respectively. Kc_{soil} is a constant value fixed at 0.2, while Kc_{veg} is calculated daily as the average of species-specific Kc_{veg} values obtained from the ratio of simulated evapotranspiration (Et, eq.3) to recorded potential evapotranspiration (Et_0) [1, 22].

Forest Water Balance

The equation of the water partition within the forest system, expressed as soil water content SWCi ($mmday^{-1}$), is determined by (eq.5):

$$SWC_i = Prec - (Int + Inf + Runoff + ETA) + \Delta SWC_{i-1} \quad 5$$

The soil water content component (SWC_i) depends on several factors: precipitation (Prec, $mmday^{-1}$), the amount of water intercepted and evaporated by the canopy surface (Int, $mmday^{-1}$), water that infiltrates the soil (Inf, $mmday^{-1}$), runoff (Runoff, mmd^{-1}) (given the absence of steep slopes leading to stagnant surface water), evapotranspiration (ETA, $mmday^{-1}$), and the change in soil water content from the previous day (SWC_{i-1}, $mmday^{-1}$). Int is function of the Leaf Area Index (LAI) and Kc_{veg}. Inf is determined by throughfall (Tf), saturation volume, and initial loss coefficient according to SCS-Curve number method [7]. Runoff is calculated by subtracting Int and Inf from rainfall. The final water balance is calculated using both bottom-up and top-down approaches for the calendar year and its quarters.

Climate Change Scenarios

To estimate the ET and ETA values and derived water forest balance under future climate change scenarios, data from the Coupled Model Intercomparison Project (CMIP6) were utilised. The study considered two Shared Socioeconomic Pathways (SSPs): SSP 8.5 and SSP 2.6 [19] for 2041-2070. To ensure a robust analysis, the averaged data from all available models was used. The standard deviation of the future climate change data was incorporated as a random factor in the predictive model for evapotranspiration-forest water balance.

The model was run several times for each of the two considered SSP scenarios. The results derived from these iterations were averaged, providing a comprehensive understanding of the potential impacts of future climate scenarios on forest water balance.

Results

Current ET and SWC simulations

The current evapotranspiration and the derived soil water content were calculated using the mass balance equation (eq.5). This allowed for the determination of the inflows and outflows that regulate the forest water balance at two different scales: species and forest canopy (Table 2, 3).

In 2022, the annual precipitation was 468.7 mm. The species-scale evapotranspiration (ETsp) and satellite-derived evapotranspiration (ETsat) were 1212.583 mm and 995.805 mm, respectively. The interception was 312.648 mm, leading to a throughfall of 155.952 mm. The runoff was 6.109 mm, resulting in an infiltration of 149.876 mm.

Table 2 – Inflow and Outflow values derived from bottom-up approach for annual and trimester period. Trim1(from Jan to Mar), Trim2 (from Apr to Jun), Trim3 (from Jul to Sept), Trim4 (from Oct to Dec).

	Prec	ETsp	Int	Tf	Run-off	Inf
2022	468.700	1212.583	312.648	155.952	6.109	149.876
Trim1	50.700	119.276	33.774	16.926	0.444	16.482
Trim2	31.000	405.615	21.062	9.938	0.057	9.881
Trim3	91.700	441.547	61.020	30.680	0.669	30.011
Trim4	295.300	246.144	196.792	98.408	4.939	93.503

Table 3 – Inflow and Outflow values derived from top-down approach for annual and trimester period. Trim1(from Jan to Mar), Trim2 (from Apr to Jun), Trim3 (from Jul to Sept), Trim4 (from Oct to Dec).

	Prec	ETsat	Int	Tf	Run-off	Inf
2022	468.700	995.805	312.648	155.952	6.109	149.876
Trim1	50.700	109.464	33.774	16.926	0.444	16.482
Trim2	31.000	365.303	21.062	9.938	0.057	9.881
Trim3	91.700	307.584	61.020	30.680	0.669	30.011
Trim4	295.300	213.453	196.792	98.408	4.939	93.503

Once the inflows and outflows from the forest system had been defined, it was possible to calculate the forest water balance, expressed as soil water content SWC (eq.5, Table 4) using the calculated evapotranspiration values.

The species-scale and stand-scale models simulated SWC values of 41225.01 mmy^{-1} and 41441.79 mmy^{-1}, respectively, closely aligning with the measured value of 42423.93 mmy^{-1} for 2022.

Table 4 – Evapotranspiration, measured SWC and simulated SWC_sp and SWC_sat values for annual and trimester period. Trim1(from Jan to Mar), Trim2 (from Apr to Jun), Trim3 (from Jul to Sept), Trim4 (from Oct to Dec).

	ET_sp	ET_sat	SWC	SWC_sp	SWC_sat
2022	1212.583	995.805	42423.929	41225.014	41441.792
Trim1	119.276	109.464	12627.000	12518.691	12528.502
Trim2	405.615	365.303	10199.100	9854.009	9894.321
Trim3	441.547	307.584	8177.700	7749.594	7883.558
Trim4	246.144	213.453	11288.100	11102.719	11135.411

Future ET and SWC estimation

By applying the SSP 2.6 and SSP 8.5 scenarios, it was possible to re-calculate the evapotranspiration and the associated inflows and outflows required for the quantification of the future forest water balance on a monthly scale (Table 5, 6).

In both scenarios, the total annual precipitation (757.6 mmy^{-1} for SSP-2.6 and 726.76 mmy^{-1} for SSP-8.5) is observed to be less than the total stand evapotranspiration (1216.496 mmy^{-1} for SSP-2.6 and 1293.347 mmy^{-1} for SPP-8.5).

Table 5 – Future Inflows and outflows values for SSP-2.6 scenario.

Months	Prec 2.6	ETsp 2.6	Int 2.6	Tf 2.6	Run-off 2.6	Inf 2.6	SWCsp 2.6
Jan	64.420	39.871	41.545	21.692	2.051	19.676	3938.619
Feb	61.380	45.433	39.191	20.369	1.821	18.608	4334.746
Mar	62.760	58.945	41.969	21.813	2.074	19.696	4085.448
Apr	66.800	85.711	43.435	22.551	2.214	20.261	4092.411
May	41.960	140.664	28.146	14.523	0.951	13.738	3827.107
Jun	26.780	166.742	17.761	9.178	0.389	8.824	3221.914
Jul	16.980	135.435	11.154	5.829	0.159	5.659	2646.540
Aug	19.900	138.307	13.073	6.817	0.217	6.567	2487.067
Sept	69.840	165.504	44.486	23.260	2.344	20.901	2407.236
Oct	112.820	138.125	74.585	38.941	6.206	33.273	2817.650
Nov	109.860	54.410	70.402	36.829	5.555	31.126	3194.757
Dec	104.100	47.350	68.999	36.049	5.348	30.503	3721.632
TOT	757.600	1216.496	494.744	257.851	29.330	228.833	40775.126

Table 6 – Future Inflows and outflows values for SSP-8.5 scenario.

Months	Prec 8.5	ETsp 8.5	Int 8.5	Tf 8.5	Run-off 8.5	Inf 8.5	SWCsp 8.5
Jan	63.360	41.929	41.986	21.820	2.075	19.738	3938.619
Feb	59.640	52.055	38.773	20.155	1.783	18.413	4334.746
Mar	54.060	67.484	35.828	18.627	1.539	17.171	4085.448
Apr	66.520	93.612	42.250	22.076	2.127	20.137	4092.411
May	41.700	146.342	27.381	14.143	0.902	13.202	3827.107
Jun	25.400	174.705	16.329	8.468	0.332	8.065	3221.914
Jul	16.520	139.311	10.969	5.751	0.155	5.606	2646.540
Aug	19.640	145.118	12.870	6.710	0.210	6.509	2487.067
Sept	61.460	178.009	41.707	21.838	2.080	19.697	2407.236
Oct	109.320	147.204	71.692	37.613	5.774	32.044	2817.650
Nov	109.980	58.150	71.577	37.582	5.760	31.751	3194.757
Dec	99.160	49.426	65.978	34.649	4.961	29.645	3721.632
TOT	726.760	1293.347	477.339	249.431	27.698	221.978	40706.783

Discussion

When ET and ETA are included in equation 5 and the other elements are kept constant, as they are independent of the physiological activity of the vegetation, the simulated values of soil water content (SWC_sat and SWC_sp) are close to those measured SWC (Table 4) (R^2species = 0.98, R^2 satellite = 0.96). This match allows us to indirectly state that the estimates of ET and ETA are realistic.

Both models demonstrated high ability in simulating soil water content (R^2species = 0.98, R^2 satellite = 0.96), further confirming the accurate estimation of evapotranspiration rates obtained through the application of biochemical and satellite models.

The water balance results (Table 4) indicate that evapotranspiration appears to consume most of the ecosystem water, while the contribution from infiltration and surface runoff is quantitatively negligible. These trends are consistent with those of semi-arid Mediterranean *Q.ilex* systems, where evapotranspiration is the main parameter driving the overall water balance, followed by interception by canopy and the contribution of groundwater cumulation that mainly occurs after extensive rainfall events [11, 14].

Local climate conditions, particularly during summer, are characterized by high temperatures and low or absent rainfall.

However, the level of soil water content never falls below the wilting point Wp (0. 194 $m^3_{H_2O}m^{-3}_{soil}$, equal to 58.2 mm), which is defined as the amount of water retained by the soil particles that is unavailable to the root’s absorption.

Based on these considerations, is possible that there is another factor within the water balance that can compensate for the significant loss of water due to evapotranspiration.

Non-Rainfall Water Input, which includes dew and fog, are atmospheric water sources that play a significant role in the hydrological cycle and water supply of terrestrial ecosystems.

These phenomena can also occur in temperate climates where average annual amount of precipitation typically balances or exceeds evapotranspiration. Dew and fog are essential sources of water for plants in different areas, including (1) arid and semi-arid regions [16]; (2) Mediterranean coastal regions [5, 31]; (3) temperate ecosystems [17]; and (4) tropical climates [8, 12]. Dew and fog are produced in the lower part of the night-time stratified atmospheric boundary layer [26].

These condensation processes occur due to the radiative cooling of the Earth's surface after sunset, which results in long-wave radiation losses during clear nights [28]. This radiative cooling leads to a decrease in surface temperature below the dew point of the adjacent air, allowing dew to form on plant surfaces and fog to form on aerosol particles activated in the atmosphere near the surface.

Coastal regions and areas near oceans are typically more conducive to dew and fog formation. As the study area is a coastal region, it has a high relative humidity of around 80 %. It also experiences significant temperature fluctuations between day and night, particularly during the dry summer season. The forest structure, characterized by the dense coexistence of scrub shrub species and tree species, can create particular sub-canopy and internal microclimatic conditions. These conditions can promote the condensation phenomena, thereby contributing to the forest's water balance as an additional source of water input.

Conclusion

A reliable estimate of the evapotranspiration values of forest stands provides insight into the interaction between various biotic and abiotic factors such as precipitation, evapotranspiration, vegetation structure and soil properties.

Vegetation exerts a role in the distribution of precipitation through its structural composition by controlling the amount of water that manages to infiltrate the soil and by drawing on the soil's water content for transpiration processes based on its physiological capacity to manage the water resource. The possibility of analysing these phenomena can provide details about how specific vegetation composition may influence the local water balance under current climatic conditions and based on expected future climate changes. The implemented multi-scale forest stand evapotranspiration and water balance models provide a valuable tool for estimating various hydrological parameters under current and future climatic conditions.

The proposed framework is particularly useful in providing guidance for the management of small, protected areas, such as the one under consideration, in which the possibility of access accurate information about the processes locally in place is an essential aspect for the success of intervention actions.

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THE AMPHIPODA AND CUMACEA ASSEMBLAGE RESPONSE TO LNG TERMINAL INSTALLATION IN ADRIATIC SEA (MEDITERRANEAN SEA)

Veronica Marusso, Benedetta Trabucco

Abstract: The Italian government have installed the first offshore liquefied natural gas (LNG) terminal that stores and re-gasifies liquefied natural gas due to the increasing of energy demand. The LGN terminal was positioned in the North Adriatic Sea and ISPRA, had monitored the installation and exercise activities for about 10 years; the monitoring program was executed in three phases: *ante operam*, during terminal installation and during terminal exercise. The monitoring process concerned different matrices: water, sediments, and biota These communities are recognized as an important tool to evaluate the environmental conditions, since they live in close contact with the seabed, etc. Our study was on two groups of macrozoobenthic crustacea: Amphipoda and Cumacea, providing information about the effect due to the first LGN terminal on this portion of benthic ecosystem. In the last years other LNG terminals were installed in the Italian Sea, the results of this study will be used to improve the planning sampling survey to understand the building effect on benthic communities.

Keywords: macrozoobenthic community, Amphipoda, Cumacea, LNG Terminal, North Adriatic Sea

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Veronica Marusso, Benedetta Trabucco, *The Amphipoda and Cumacea assemblage response to LNG terminal installation in Adriatic Sea (Mediterranean Sea)*, pp. 252-264, DOI: 10.36253/979-12-215-0556-6.22

Introduction

The Italian government have installed the first offshore liquefied natural gas (LNG) terminal that stores and re-gasifies liquefied natural gas due to the increasing of energy demand. The LGN terminal was positioned in the North Adriatic Sea, nearby the city of Chioggia, and ISPRA, the Institute for Environmental Protection and Research, had monitored the installation and exercise activities for about 10 years. The monitoring program was executed in three phases: *ante operam*, during terminal installation and during terminal exercise. The monitoring process concerned different matrices: water, sediments, and biota; in this study, the results carried out by the macrozoobenthic community analysis, are shown. These communities are recognized as an important tool to evaluate the environmental conditions, because the animals that make up these communities live in close contact with the seabed, have a long-life cycle and can indicate a seabed perturbation, moreover these animals play an important role in the marine food chain, as they constitute the food for many benthic fishes. [1, 2, 3].

This is the first offshore LNG terminal in Italy and the first in the world Gravity Based Structure (GBS) for unloading, storing and re-gasifying [4, 5, 6]. The realization of such structures could generate different impacts both on the water column and on the sea bottom. Up to now several studies have proved that offshore activities can induce changes in the characteristics of sediment. In particular, the presence and the activity of these structures might have some sort of impact on benthic communities inhabiting the surrounding seabed. The variations in sediment physical features (e.g. sediment grain-size, sedimentation rates) might determine qualitative and quantitative changes in the structure of soft-bottom benthic communities living immediately around the installations. [7, 8, 9, 10, 11, 12, 13, 14]. Regarding GBS LNG terminal being the first in the world, very few studies on benthic communities were available, nevertheless on potential impacts on marine ecosystem due to this kind of structure [15, 16].

To verifying possible impacts on marine environment associated to the project, on behalf of Adriatic LNG, acting under the vigilance and policy guidance of the Italian Ministry for the Environment, in 2005 we ISPRA elaborated and then carried out a multidisciplinary monitoring plan. The monitoring plan provides three phases: 1) before and 2) during the construction of the structures, and 3) during terminal operation. With the purpose of monitoring disturbance degree on surrounding environment data on sediment grain size and macrozoobenthic community around the Terminal were analysed. These assemblages are commonly used as environmental indicators. They have such particular dynamics they permit an integrated valuation of the space – temporal alteration of the ecosystem. [17, 18, 19].

In this paper we report results regarding the potential effects of terminal installation and storage activities on two groups of crustacea belonging to macrozoobenthic community: Amphipoda and Cumacea, for a period ranging from 2006 to 2015. Benthic assemblage structure was examined focusing the attention on compositional characteristics of the macrofauna at increasing distances from the LNG structure. This study provided information about the effect due to the first LGN terminal in our Sea on two benthic *taxa* and allowed to collect information about temporal change of the Amphipoda and Cumacea communities. In the last years other LNG terminals were installed in the Italian Sea, the results of this study then could be used to improve the planning sampling survey to understand the building effect on benthic communities.

Material and methods

The terminal is located approximately 12 km away from the nearest Adriatic Sea coast (Porto Levante, Rovigo, Italy). A radial sampling design of 13 stations (3 stations at 100 m, 6 stations at 200 m, 4 stations at 500 m), arranged at increasing distances from the terminal site and 3 control site 4 km apart from terminal, was developed [20, 8, 21] were chosen (Figure 1). Sampling surveys took place throughout the period 2006 - 2015. In June 2006 a preliminary survey was carried out before the construction activities of the terminal (survey 1) in October 2008 a survey was carried out during yard activities of the terminal construction (survey 2); then during the following years more surveys were carried out after terminal installation (respectively 3, 4, 5, 6, 7, 8). Sediment was collected around the terminal with a Van Veen grab (0.1 m^2), taking two samples for each station. The samples were then processed through a sieve (1mm mesh-size) and the retained fraction was fixed in 4 % formaldehyde buffered with $CaCO_3$. In laboratory samples were then sorted with the use of microscopes into main taxonomic groups (Crustacea Peracardia: Amphipoda and Cumacea) and identified at the lowest possible taxonomic level (i.e. species), in addiction ecology of all species was collected and grouped into nine different bottom types: mixed, silty, soft, organic matter, hard, sandy, detritical, vegetable and gravel." [22, 23, 24, 25, 26].

Total macrofauna abundance (N), total species richness (S), Shannon index (H') and equitability (J'), Margalef specific Richness (d) were calculated in order to explore quantitative and qualitative changes in assemblage structure among stations and surveys. Similarity matrices were calculated using the Bray-Curtis similarity index [24] and data were graphically represented using non-metric

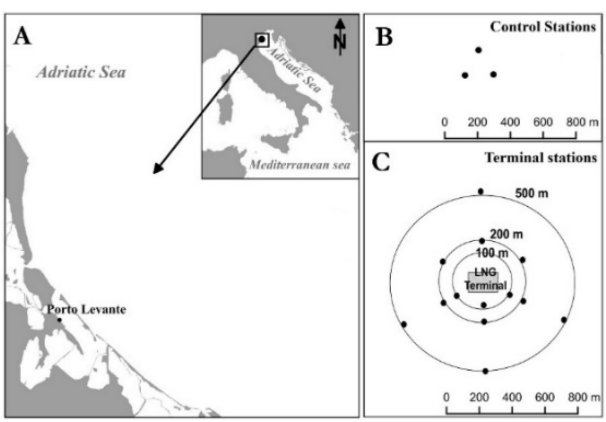

Figure 1 – Study Area (A); Control stations (B) sampling stations around the Terminal structure (C).

Multi-Dimensional Scaling (nMDS) ordinations. The grain size percentage of gravel, sand, silt and clay were provided for each station and survey, and similarity matrices were calculated using the Euclidean distance and data were graphically represented using non-metric Multi-Dimensional Scaling (nMDS) ordinations.

Results

A total of 4218 individuals belonging to 96 species of Peracarida belonging to the *taxa* of Amphipoda and Cumacea were collected. The table 1 shows the species collected during the 8 surveys.

Table 1 – List of species belong to Amphipoda and Cumacea collected during the 8 surveys.

Amphipoda	
Ampeliscidae	*Ampelisca diadema* (A. Costa, 1853)
	Ampelisca ledoyeri Bellan-Santini & Kaim-Malka, 1977
	Ampelisca massiliensis Bellan-Santini & Kaim-Malka, 1977
	Ampelisca pseudospinimana Bellan-Santini & Kaim-Malka, 1977
	Ampelisca rubella A. Costa, 1864
	Ampelisca ruffoi Bellan-Santini & Kaim-Malka, 1977
	Ampelisca sarsi Chevreux, 1888
	Ampelisca spinifer Reid, 1951
	Ampelisca spinipes Boeck, 1861
	Ampelisca tenuicornis Liljeborg, 1856
	Ampelisca truncata Bellan-Santini & Kaim-Malka, 1977
	Ampelisca typica (Spence Bate, 1857)
Aoridae	*Aora spinicornis* Afonso, 1976
	Autonoe spiniventris Della Valle, 1893
Argissidae	*Argissa hamatipes* (Norman, 1869)
Atylidae	*Nototropis guttatus* (A. Costa in Hope, 1851)
	Nototropis massiliensis (Bellan-Santini, 1975)
	Nototropis vedlomensis (Spence Bate & Westwood, 1862)
Bathyporeiidae	*Bathyporeia lindstromi* Stebbing, 1906
Calliopiidae	*Apherusa vexatrix* Krapp-Schickel, 1979
Caprellidae	*Liropus elongatus* Mayer, 1890
	Phtisica marina Slabber, 1769
	Pseudolirius kroyeri (Haller, 1879)
Cheirocratidae	*Cheirocratus assimilis* (Lilljeborg, 1852)
	Cheirocratus sundevallii (Rathke, 1843)
Corophiidae	*Apocorophium acutum* (Chevreux, 1908)
	Corophium orientale Schellenberg, 1928
	Leptocheirus bispinosus Norman, 1908
	Leptocheirus guttatus (Grube, 1864)
	Leptocheirus longimanus Ledoyer, 1973
	Leptocheirus mariae Karaman, 1973
	Leptocheirus pectinatus (Norman, 1869)
	Medicorophium aculeatum (Chevreux, 1908)
	Medicorophium rotundirostre (Stephensen, 1915)
	Medicorophium runcicorne (Della Valle, 1893)
Dexaminidae	*Dexamine spiniventris* (A. Costa, 1853)
	Dexamine spinosa (Montagu, 1813)
Eusiridae	*Eusirus longipes* Boeck, 1861
	Rhachotropis ind. S.I. Smith, 1883
Gammaridae	*Gammarus aequicauda* (Martynov, 1931)
	Gammarus insensibilis Stock, 1966
Iphimediidae	*Iphimedia gibbula* Ruffo & Schiecke, 1979
Ischyroceridae	*Centraloecetes dellavallei* (Stebbing, 1899)
	Ericthonius brasiliensis (Dana, 1853)
	Ericthonius punctatus (Spence Bate, 1857)
	Siphonoecetes ind. Krøyer, 1845
Kamakidae	*Cerapopsis longipes* Della Valle, 1893
Leucothoidae	*Leucothoe incisa* Robertson, 1892
	Leucothoe oboa Karaman, 1971
	Leucothoe occulta Krapp-Schickel, 1975
	Leucothoe serraticarpa Della Valle, 1893
	Leucothoe spinicarpa (Abildgaard, 1789)
Liljeborgiidae	*Liljeborgia dellavallei* Stebbing, 1906
	Liljeborgia psaltrica Krapp-Schickel, 1975

Lysianassidae	*Lysianassa caesarea* Ruffo, 1987
	Lysianassa costae H. Milne Edwards, 1830
Maeridae	*Ceradocus (Ceradocus) orchestiipes* A. Costa, 1853
	Hamimaera hamigera (Haswell, 1879)
	Maera grossimana (Montagu, 1808)
	Maera sodalis Karaman & Ruffo, 1971
	Othomaera schmidtii (Stephensen, 1915)
Megaluropidae	*Megaluropus* ind. Hoek, 1889
Melitidae	*Abludomelita gladiosa* (Spence Bate & Westwood, 1862)
Nannastacidae	*Campylaspis glabra* Sars, 1878
	Procampylaspis bonnieri Calman, 1906
Oedicerotidae	*Bathymedon* ind. G.O. Sars, 1892
	Deflexilodes acutipes (Ledoyer, 1983)
	Deflexilodes griseus (Della Valle, 1893)
	Deflexilodes subnudus (Norman, 1889)
	Kroyera carinata Spence Bate, 1857
	Perioculodes longimanus (Spence Bate & Westwood, 1868)
	Westwoodilla rectirostris (Della Valle, 1893)
Photidae	*Gammaropsis dentata* Chevreux, 1900
	Gammaropsis maculata (Johnston, 1828)
	Gammaropsis ulrici Krapp-Schickel & Myers, 1979
	Latigammaropsis togoensis (Schellenberg, 1925)
	Photis longicaudata (Spence Bate & Westwood, 1862)
Phoxocephalidae	*Harpinia dellavallei* Chevreux, 1911
	Metaphoxus ind. Bonnier, 1896
Stenothoidae	*Stenothoe* ind. Dana, 1852
Tryphosidae	*Orchomene humilis* (A. Costa, 1853)
	Orchomene massiliensis Ledoyer, 1977
	Orchomene similis Chevreux, 1912
	Tryphosa nana (Krøyer, 1846)
Cumacea	
Bodotriidae	*Bodotria scorpioides* (Montagu, 1804)
	Iphinoe rhodaniensis Ledoyer, 1965
	Iphinoe serrata Norman, 1867
	Iphinoe tenella Sars, 1878
Leuconidae	*Eudorella nana* Sars, 1879
	Eudorella truncatula (Bate, 1856)
	Leucon (Leucon) mediterraneus Sars, 1878
Diastylidae	*Diastylis cornuta* (Boeck, 1864)
	Diastylis neapolitana Sars, 1879
	Diastylis richardi Fage, 1929
	Diastylis rugosa Sars, 1865
	Diastylis tumida (Liljeborg, 1855)

The highest value of abundance N (806 individuals) was observed at the first survey (1) while the lowest value was recorded at the survey 4 (Fig 2a). The highest value of number species (S) was observed at survey 7, while the lowest at survey 5 (Fig 2b).

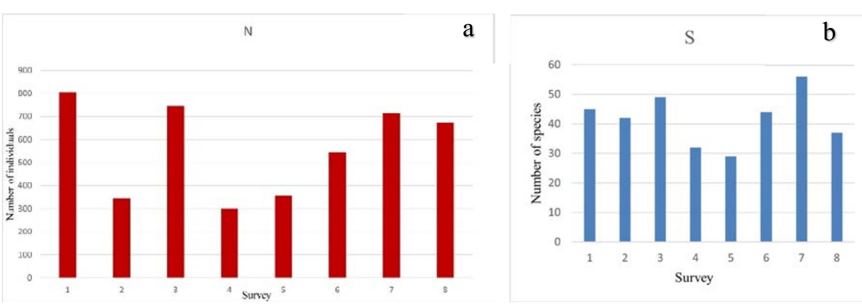

Figure 2 – The average value of Abundance N (a) and Number of species S (b) calculated for each survey.

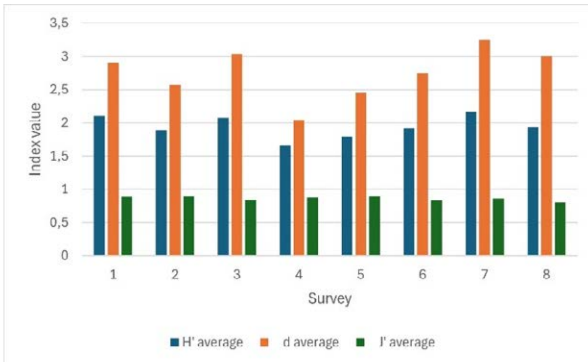

Figure 3 – The average value of H’, d and J’ index calculated for each survey.

The average value of index H’, d and J’ was calculated for each survey (Fig. 3), the highest value of H’ was observed in the survey 7, while the lowest in the survey 4, the highest value observed for the index d was in the survey 7 while the lowest in the survey 4, at the end the J’ index showed the highest value in the survey 2 and the lowest in the survey 8.

All stations collected during the 8 surveys were showed at the MDS plot. A weak difference among the stations near and far from the terminal installation was observed, indeed it is possible to note that the stations near the terminal were generally separated from the others. It is possible observe a low difference among the eight surveys analyzed especially in the surveys 4 and 5 (Fig 4a). Also, the centroid analysis showed the difference among the surveys: the Peracarida community observed during the survey 2 (during the terminal installation) showed differences from that observed in survey 1, while in the survey 3 the community seem to be more like survey 1then survey 2 (Fig 4b). The assemblage observed in the surveys 4, 5, 6 and 7 showed weakly mutual different each other, while the community observed in the survey 8 seemed to be like the survey 3.

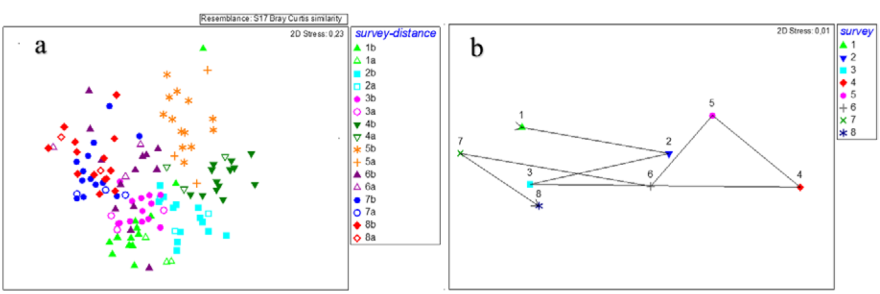

Figure 4 – a) The MDS plot shows the similarity among the stations and the surveys calculated on the Peracarid community. Number from 1 to 8 indicated the surveys, the empty symbol represents the stations near to the terminal (call a), the full symbols represent the stations far from the terminal at a distance at greater than 100 meters, (call b). b) The plot shows the centroid distance among the surveys.

The MDS plot (Fig 5) showed the stations similarity carried out on the sediment features: two different groups of stations were plotted: one at the lower part of the graphic characterized by the gravel presence, and another in the higher part of the plot the stations with the sand, clay and silt where weakly difference among the stations near and far from the terminal installation and among the surveys was observed. Analysis of the centroids showed that the granulometric conditions produced by the installation of the terminal seemed to return in a condition more similar to the initial conditions one (survey 1).

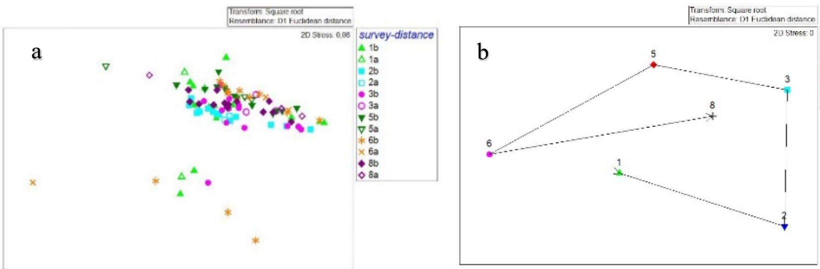

Figure 5 – a) The MDS plot shows the similarity among stations and survey calculated on grain size. Number from 1 to 8 indicated the surveys, the empty symbol represents the stations near to the terminal (call a), the full symbols represent the stations far from the terminal at a distance at greater than 100 meters, (call b). b) The plot shows the centroid distance among the surveys calculated on grain size.

Information about ecology of each species collected was gathered and grouped in nine different bottom types: mixed, silty, soft, organic matter, hard, sandy, detritical, vegetable and gravel. Figure 6 showed the abundance of species and their respectively ecology only for the community belong to the station near the terminal (T4, T16 and T27) for each survey.

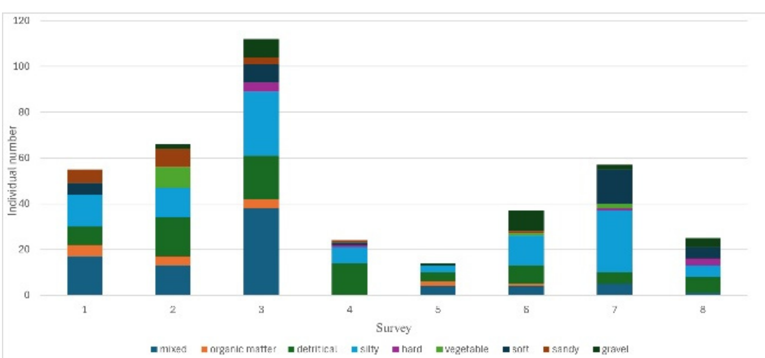

Figure 6 – The ecology of specie observed at the three stations close to the terminal installation (T7, T17 and T27) in each survey.

Species with mixed and detritical ecology showed an increase of their abundance after construction of the terminal structure (survey 3) and a decrease on the following surveys. The species related to organic matter showed a continuous decrease from the first to the last survey. Species living in silty, soft and gravel bottom showed a fluctuating trend, while species linked to the hard bottom showed a peak in the survey 3 followed by a decrease in the surveys 4, 5 and 6, and a recovery in the survey 7. For the species linked to vegetable bottom a peak was observed during the survey 2, during the terminal installation, and finally, sandy species showed a peak in the survey 2 and then a decrease at the following surveys.

Figure 7 –The most abundant specie at each survey.

The most abundant species collected were Amphipods belonged to Ampelisca genera, while the Cumaceans were represented generally with few individuals that belonged to few species (Fig. 7). *Ampelisca diadema*, *Ampelisca typica* e *Ampelisca tenuicornis* were respectively the most abundant species of surveys 1 and 4, while in the survey 2 *Ampelisca sarsi*, *A. typica* and *Leucothoe oboa*. *A. tenuicornis*, *A. diadema* and *A. typica* were the most abundant in the survey 3. *A. tenuicornis*, *A. typica* and *Ampelisca ledoyeri* were the most abundant in the surveys 5. The Caprellidae *Phtisica marina* and *A. tenuicornis* and *A. ledoyeri* showed the hight number of individuals in the survey 6, while *A. typica*, *P. marina* and *Photis longicaudata* were the most abundant in the survey 7. At the end *A. typica*, *A. diadema* and *Ericthonius punctatus* were the species with the hight number of individuals in the survey 8.

Discussion

Cumaceans and Amphipods are benthic organisms, generally 1–10 mm in size, that are strongly linked to the seabed where they can burrow tunnels. These organisms are characterized by morphological features that differentiate them from other peracarid crustaceans. Cumaceans together with Amphipods live in seawater from intertidal shelves to great depths [28] but can also be found in brackish water and rivers [29]. They can be influenced by the type and nature of the sediment, as well as its organic matter content, which can generate changes in their abundance [30, 31]. These taxa represent an important link in marine trophic webs because these animals are common food for many species of fish living near the bottom. [32]. They are also known as indicators of organic enrichment [30] and the eutrophication of soft bottoms [34] and are therefore often used together with other benthic organisms to monitor environmental quality [35, 36], as also requested by the major European directives (WFD/2000/60/EC; MSFD/2008/56/EC).

The study showed that the Terminal installation generated a change on the Peracarid benthic community, principally focused on the period during the installation and at the stations near the structure. The lowest N value observed in the survey 2, is caused by sediment movement resulting from the installation activities, nevertheless the high value of the number of specie observed in this survey indicate that the assemblage has preserved the biodiversity as showed by the indexes (H' d and J). Nevertheless, after the terminal installation effect, the community on average recovered the initial abundance. In fact, our studies seemed to reveal that changes in benthic assemblages were mostly linked to the construction phase of the LNG plant, and, to some extent, are limited to the first period of activity of the terminal [13]. During the following surveys just some oscillations were observed, in terms of abundance and species number. These oscillations are most likely due to natural events, which could determine the sediment grain size modification, and then change in the benthic community structure [37, 38, 39, 40].

From the 1 to the 8 surveys, following the sediment modifications, it was observed a change of the dominant species at each survey, the most abundant taxon at most of the surveys was the taxon of Ampelisca. The most abundant species in the survey 1 were linked to mixt and silty sediment (*A. diadema* and *A. typica*), while in the survey 2 the most abundant species prefer organic matter and mixed sediment (*A. sarsi* and *A. typica*). The presence of this species is compatible with the effects product by the installation activity that can caused sediment movement and consequent resuspension of organic matter.

In the survey 3 the most numerous species collected were detritic and mixed respectively (*A. tenuicornis* and *A. diadema*), so after human activity it was possible observed the effects of Terminal construction. In the assemblage collected during the survey 4 it was possible to observe came back the most numerous species *A. typica* that was link to silty sediment with *A. diadema*, instead linked to mixed bottom. The most abundant species link to detritic bottom was observed in the survey 5 and 6 and at the end in the survey 7 and 8 the most abundant species *A. typica* was linked to silty bottom and mixed sediment *A. diadema*.

The Peracarida community appeared to return to similar conditions observed during the survey 1 after 4 years.

Conclusions

Environmental quality assessment, according to the guidelines, involves the use of a species list that associates each species with an ecological class based on the group's ability to indicate a disturbed or undisturbed environment. The collection of data allows species lists to be updated with new records, therefore representing an important aspect for the conservation of marine ecosystems and for peracarids taxonomy insiders.

The scarcity of amphipods and in particular cumacean taxonomists and experts is another predicament: in fact, the taxonomist's profession requires many years of study and practice, and unfortunately the existing reference bibliography used as a credential tool for identification purposes is limited and often outdated. We hope more studies on minor taxa, such as peracarids in general, will be published in order to address this knowledge gap.

The data obtained by the sample analysed confirm findings from similar studies conducted in other coastal areas and highlight the challenges in predicting the processes and timing of colonization by macrozoobenthic organisms. Monitoring activities remain highly relevant because the evolution of the benthic population needs to be studied and evaluated over time. The collection of a longtime data series is expected to bring more light on the effects of the presence of the LNG structure on the surrounding marine seabed. First analyses seem to indicate that the effects on benthic macrofauna, if any, were limited to the period of the construction yard, and some signal of alterations in diversity measures were found for the subsequent 4 years. This research allowed us to gain a high amount of data that could provide a reference for this type of studies in the future and will let us to optimize field and laboratory work, addressing monitoring actions at the best.

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A METHODOLOGICAL APPROACH TO ASSESSING THE CONSERVATION STATUS OF COASTAL HABITATS: THE CASE STUDY OF CALABRIA (SOUTHERN ITALY)

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Abstract: The Mediterranean coasts are threatened by human activities that cause changes andalterations in the coastal ecosystems. This study aims to assess the impact of urbanisation on the conservation status of EEC Directive 43/92 habitats. A total of 73 vegetation relevés were carried out, which allowed us to recognise 13 habitats. The total diversity of plant species per habitat was measured with the Shannon-Wiener Index (H') used to assess naturalness (Na), considering native, alien and disturbance species separately. The analysis showed that the highest values of H' were found in habitats 1430, 2110 and 2240 while lower values were observed in habitats 2270*, 2250*,2210. The results showed that habitats 2270* and 2250* show a lower naturalness value than habitats 1210, 1240, 2110 and 2240, with higher naturalness values and therefore a low disturbance. This methodology can be used by managers to identify the most sensitive coastal dunes and implement a conservation strategy.

Keywords: Diversity; Naturalness; Directive Habitat; alien and disturbing species.

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Antonio Morabito, Carmelo Maria Musarella, Giovanni Spampinato, Giuseppe Caruso, *A methodological approach to assessing the conservation status of coastal habitats: the case study of Calabria (Southern Italy)*, pp. 265-273, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.23

Introduction

Coastal ecosystems are particularly vulnerable and highly endangered, as they are considered among the most threatened by urbanization and anthropogenic fragmentation [1, 2,3]. Since the 50s and 60s of the last centuries, coasts of Mediterranean basin, have been deeply anthropized becoming very attractive tourist destinations in the world [4]. This drastically changed the vegetation and ecological diversity formerly characterising these habitats [5, 6, 7, 8, 9, 10, 11, 12].

Coastal exploitation for tourism has promoted the rapid spread of ruderal and synanthropic species in coastal ecosystems, as well as the establishment of invasive alien ones [13, 14, 15]. These changes profoundly affect the plant communities of coastal habitats, sometimes leading to the disappearance of typical species. [16,17]. Invasions of alien species are among the most serious pressures on ecosystems and one of the main threats to biodiversity conservation [18], especially for coastal ecosystems [19]. Many authors have pointed out that the spread of synanthropic and alien species in coastal ecosystems also causes serious disturbances in physical processes, and that the loss of diversity of native psammophilous species reduces the ability of ecosystems to maintain their functioning in an environment more affected by climate change. [2, 3].

Habitats play a fundamental role in conserving biodiversity and ecosystem services, and therefore merit specific protection measures. [20,21]. From this perspective, habitat monitoring is of great importance both for assessing the conservation status of the environment and for identifying priorities and critical issues in the management of the coastal ecosystem [22]. According to Carboni et al. (2009) [20], the vegetation of coastal habitats can be used as a good indicator to assess the biodiversity and conservation status of coastal habitats.

Mediterranean coastal ecosystems host high ecological diversity due to both diversity in species composition and environmental heterogeneity [23, 7]. Today, the designation of protected areas (PA) and the implementation of the Natura 2000 network are central to reversing the loss of biodiversity in Europe. [24]. Several scientific approaches are focused on quantifying human-induced change using indices such as species richness and diversity in order to assess the conservation status of coastal dunes [25,26, 27]. In ecological studies, the Shannon-Wiener diversity index (H') [28], is frequently used in vegetation analysis [20], and in methods applied to the assessment of the conservation status of coastal habitats [29].

The aim of this research, which takes the coastal habitats of Calabria as a case study, is to propose a methodology useful for assessing the conservation status of coastal environments. This methodology is a biodiversity assessment based on the analysis of vegetation and landscape, considering human the impact on coastal habitats. The coastal vegetation of Calabria is quite well known thanks to many studies, mainly performed applying the phytosociological method by various authors [30,31,32,33,34,35]. In particular, this study aims to assess the conservation status of coastal habitats by applying diversity indices to the species composition of the phytocenosis; geographicinformation system (GIS), and analysis of the habitat diversity through the study of vegetation.

Materials and methods

As a case study, we analyse coastal habitats of the Calabria region (Southern Italy) in the central Mediterranean, which has a coastline of about 700 km [36].

Coastal habitats analysis was based on vegetation relevés carried out from 2018 to 2021, applying the phytosociological method of the Zurich-Montpellier school. Seventy-three unpublished relevés with 367 species were carried out (Supplementary Materials Appendix 1). The matrix of phytosociological relevés was analysed by a multivariate analysis for the definition of statistical based cenological assemblages. The abundance-dominance cover values Braun-Blanquet scale were converted to the numerical value scale proposed by Van der Maarel [37]. The software used for the organisation of the raw data and the subsequent statistical analyses were: Microsoft Excel 2010; PAST version 4.13; R 4.1.1 R Core Team 2021.

The cluster analysis of the relevés matrix used the average linkage criterion (UPGMA) and the Chord distance algorithm to identify homogeneous plant assemblage. The interpretation of habitats was performed according to the following literature [38, 39, 40, 41, 42, 43].

Plant species diversity was assessed by combining the relevés for each habitat type and calculating the Shannon-Wiener H′ index for each relevé, then averaging it across the habitat relevés [28].

$$H' = -\sum_{j=1}^{s} pi \ \log pi$$

where pi = coverage of the ith species compared to the entire community; S= number of species.

As highlighted by Grunewald and Schubert [26], Pinna et al.; [44], Caldaresi et al., [45], the Shannon-Wiener index (H ′) allows the evaluation of the Naturalness (N)of a habitat, but in addition to considering native and alien species, we have also considered disturbance species, so species typical of synanthropic habitats (e.g. uncultivated land, ruderal environments, weedy species, etc-).

$$N = H' \text{ (without alien and disturbing plant species) } / \ H'$$

The N index assumes values ranging from 0 to 1, where 0 indicates that plant diversity consists entirely of alien and disturbance species, while 1 indicates the absence of the latter in phytocenosis. Alien species were identified in accordance with the Portal to the Flora of Italy [46], while plant communities and disturbance species were verified considering the "Prodromo della vegetation d'Italia" [47] as well as the contributions of other authors [30,9]. In particular, syntaxonomic references of plant communities belonging to the anthropogenic vegetation classes *Stellarietea mediae* Tüxen, Lohmeyer & Preising ex Von Rochow 1951 and *Galio aparines-Urticetea dioicae* Passarge ex Kopecký 1969 were taken for disturbance species according to Biondi & Blasi [45].

Results

The analysis of the relevés carried out on coastal vegetation identified the following habitat types of Annex 1 to European Directive 43/92: 1210 - Annual vegetation of drift lines;); 2110 - Embryonic shifting dunes; 2120 - Shifting dunes along the shoreline with *Ammophila arenaria* (‘white dunes’); 2210 - *Crucianellion maritimae* fixed beach dunes, 2230* - Malcolmietalia dune grasslands; 2240 - Brachypodietaliadune grasslands with annuals; 2250* - Coastal dunes with *Juniperus* spp.; 2260 - Cisto-Lavanduletalia dune sclerophyllous scrubs; - 2270* Wooded dunes with *Pinus pinea* and/or *Pinus pinaster*; 1240 - Vegetated sea cliffs of the Mediterranean coasts with endemic Limonium spp.; 1410 - Mediterranean salt meadows (*Juncetalia maritimi*); 1420 - Mediterranean and thermo-Atlantic halophilous scrubs (Sarcocornetiea fruticosi); 1430 - Halo-nitrophilous scrubs *(Pegano-Salsoletea)*.

The plant communities that characterized the coastal habitat types have a distribution that follows the typical succession of other Mediterranean coastal, begins with the annual vegetation on the coastline and continues with the psammophilous herbaceous communities of the embryonic and mobile dunes (habitat 1210; 2110; 2120) up to the shrub or forest communities on the stabilized dunes (2230;2240;2250*;2260 and 2270*).

The biodiversity values of the coastal habitats (Figure 1) show that the Shannon-Wiener index (H^{+}) species is higher for habitats 1430, 2260, 2110 and 2240. Lower values have been found in habitats 1420, 2250* and 2270*.

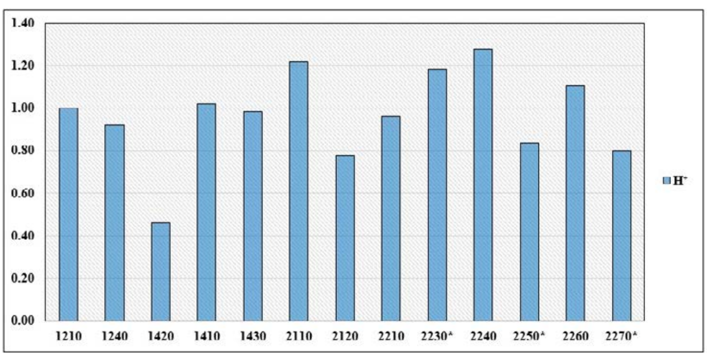

Figure 1 – Biodiversity values Shannon-Wiener index (H’) in the coastal habitats.

The highest naturalness values (N), equal to 1, were found in habitats 1240, 1420, 1410, 2230 (Fig. 2), while the lowest values, about 0.8, were observed for habitats 2270*, 2250* and 2210, which have been found to be more susceptible to disturbance because they are home to a high number of synanthropic species as *Galactites tomentosus* Moench*, Reichardia picroides* (L.) Roth) and alien species as *Acacia saligna* (Labill.) H.L. Wendl. *Oxalis pes-caprae* L.

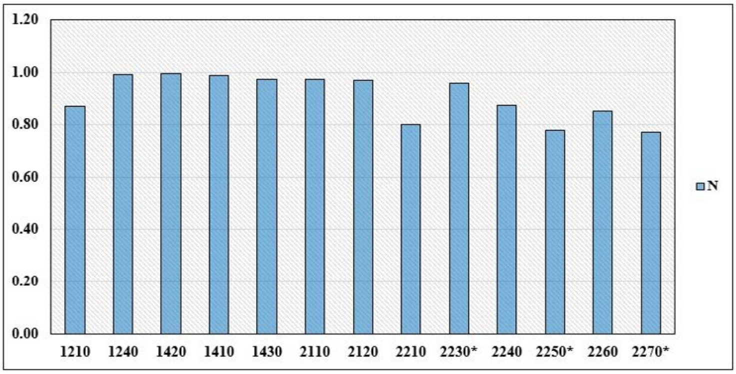

Figure 2 – Values of the naturalness index (N) in the coastal habitats.

Figure 3 shows that in habitats 2270*, 2250*, 2230 2210 the *H' values* of disturbance species (*H' dist*.) are higher than the H^+ values of typical species (H*'* typ.),unlike habitats 1210, 1240, 1410, 1420, and 2260 where the greatest diversity (H^+) isrepresented by typical species.

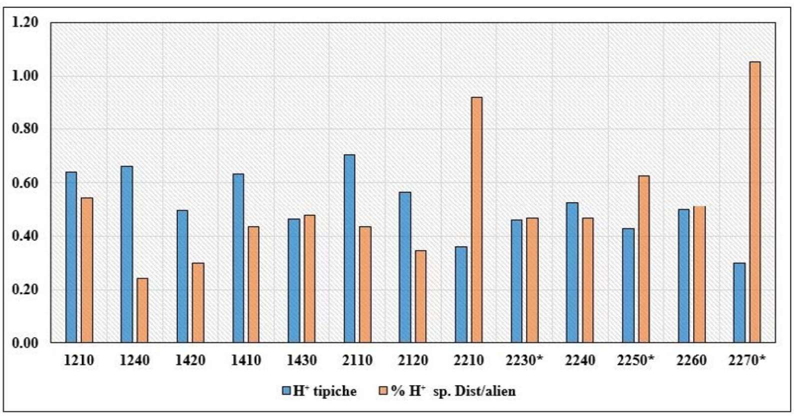

Figure 3 – Percentage values of the H' index of typical species (% H'sp. Typ) and those ofdisturbance and alien species (% H' sp. Dist/Alien) in coastal habitats.

Discussion and conclusions

The analysis of habitat plant communities using naturalness indices based on biodiversity was found to be helpful in assessing the impact of human activity on coastal habitats, conversely to what has been shown in other studies [48]. The low values of naturalness index (Na) are not only due to the presence of alien taxa in the study area, but also to the presence of synanthropic species, which are indicators of disturbance. The analysis carried out shows that coastal habitats 2270* and 2250 have low naturalness values due to the significant contribution to the biodiversity of alien and disturbing species, highlighting that, in agreement with other studies [49], the seaside tourist exploitation of the coasts promotes the spread of invasive and disturbing species that constitute the most important threat to coastal habitats not only in open habitat closer to the coastline but also and above all in more stabilized ones, such as grey dunes and forests. Among these, we can observe habitat types 2270*, 2250* and 2210, the latter in agreement with other studies [6,50] are considered the most sensitive to anthropogenic disturbance. Habitat 2210 (*Crucianellion maritimae* fixed beach dunes) is considered at risk in all Mediterranean coasts; while habitat 2250* following Acosta et al., [5] also in Calabria is currently limited to the few coastal stretches not exploited for tourists or residential purposes. Habitat 2270* is the one that has the greatest presence of anthropogenic species in agreement with Bonari et al [51] and Sarmati et al., [10] for other Italian territories. Probably one of the main causes for the establishment of these weeds and ruderal communities is trampling consequent to tourist exploitation. Habitat 2250* is also in bad conservation status, in agreement with other studies [12] and shows a marked area reduction due to human activity throughout the Mediterranean biogeographical region. According to Acosta [52], the species richness of coastal dune habitats is maximum in the intermediate dune, while synanthropic species are more frequent in the inland habitat.

The presence and spread of alien species within the wooded dunes tend to create further critical issues for the protection of coastal habitats, modifying their diversity in different ecosystems [53], including *Acacia saligna* used for reforestation, produces a litter that takes a long time to degrade, and this negatively affects soil availability.

Our findings emphasize the need to prioritize monitoring activities in wooded dunes and stable dunes due to the higher presence of alien and disturbance species in these habitats that reduce biodiversity and pose a threat to the conservation of these habitat types.

The use of diversity indicators in vegetation analysis is suitable for identifying the changes caused by invasive and synanthropic species. This approach can also be used to monitor and evaluate the conservation status of habitats of community interest according to EEC Directive 43/92. Overall, the methodological approach used can provide valuable support for implementing a conservation strategy that aligns with the integrated management of coastal ecosystems in the Mediterranean.

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MAPPING SUBMERGED VEGETATION AND WATER QUALITY USING MULTI- AND HYPERSPECTRAL IMAGERY OF ORISTANO GULF (ITALY)

Monica Pinardi, Salvatore Mangano, Andrea Pellegrino, Alice Fabbretto, Claudia Giardino, Andrea Taramelli, Andrea Satta, Mariano Bresciani

Abstract: Shallow water habitats are among the most important and productive ecosystems on the planet. These ecosystems, which include seagrass meadows, are important biodiversity hotspots. The spread of seagrass can be managed by looking at the seabed cover and how it changes over the year. To this end, satellite-derived products of substrate and vegetation cover at different spatial-temporal resolutions can help water managers and users to better understand and manage seagrass beds in shallow waters. The main objective of this study is to test and apply algorithms to obtain bottom substrate, canopy cover together with water quality maps (e.g. SPM, Chl-a) from hyperspectral (e.g. PRISMA) and multispectral (e.g. Sentinel-2) satellite data. The study is developed in the framework of the PRISMA SCIENZA OVERSEE project and focuses on the coastal areas of the Gulf of Oristano (Sardinia, Italy). Changes in substrate cover have been tracked for the period May-October 2022. Spatio-temporal variability of *Posidonia oceanica* has been studied and discussed in relation to environmental features and human activities.

Keywords: Seagrass, Remote Sensing, PRISMA, Water Quality

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Introduction

Shallow water ecosystems, which include seagrass meadows, coral reefs and macrophyte beds, are important biodiversity hotspots and nurseries for many species that live at or near the bottom [1]. In saline and brackish waters, seagrasses often develop along gently sloping, safe beaches and live at depths of 1 to 3 metres [2], as photosynthesis requires light. *Posidonia oceanica* is a seagrass habitat that is receiving increasing attention in Marine Protected Areas (MPAs) planning processes [3] due to its importance in providing many ecosystem functions and services.

P. oceanica is a priority habitat (Habitat Directive 92/43/CEE) and needs to be monitored over time to estimate the impact of human activities on meadows, thus supporting the implementation of conservation measures [4]. The majority of seagrass bed losses in recent decades can be attributed to human activities, both directly and indirectly. This fragmentation of seagrass meadows can affect the fauna migration, as well as the rate of erosion at the seagrass bed boundaries. Some seagrass meadows that grow quickly can recover from disturbance, but many grow slowly over many years and are likely to be slow to recover, making them the most vulnerable. The spread of seagrass can be managed by looking at the seabed cover and how it changes over the year. To this end, satellite-derived products of substrate and vegetation seabed cover at different spatial-temporal resolutions can help water managers and users to better understand, exploit and manage seagrass meadows in shallow waters [5,6].

Water quality status plays a critical role for biological life, from primary producers (e.g. phytoplankton and seagrass) to fish communities. Water turbidity can be increased by various human-related activities, such as agricultural run-off and river and coastal bank erosion. When fertilizers and sediment are washed into the water from the land, they induce algal blooms on one side, suffocate seagrass on the other, and block sunlight on both. Characterisation of turbidity, suspended particulate matter (SPM) and chlorophyll-a (Chl-a) concentration can help water managers and users to understand the degree of water transparency and the trophic status of the ecosystem. As for seagrass coverage, optical remote sensing (RS) provides relevant observations and knowledge on the spatial-temporal variability of water quality parameters [7]. According to a recent review of the literature by Appolloni et al. [8], there are still not many studies that monitor *P. oceanica* beds over time, despite the fact that RS is widely acknowledged as a very useful technology for mapping seagrass meadows and habitats. This is likely because affordable RS imagery has a low resolution that prevents small-scale monitoring.

In this study we evaluate the *P. oceanica* cover distribution and density in the Gulf of Oristano (Sardinia, Italy) located in the Mediterranean Sea, an ecosystem that support biodiversity and sustains a vital ecosystem for the preservation of coastal areas. The main objective of this study is to test and apply algorithms to obtain bottom substrate maps together with water quality maps (e.g., SPM, Chl-a) from satellite data. In addition to the products obtained with hyperspectral imagery (e.g. PRISMA), multispectral (e.g. Sentinel-2) data with high spatial resolution and revisit time were used to better evaluate the evolution of the water characteristics of the study area. The study is developed in the framework of the PRISMA SCIENZA OVERSEE project and it focuses on the coastal areas of the Gulf of Oristano (Sardinia, Italy).

Material and Methods

The Gulf of Oristano on the Italian island of Sardinia (Figure 1), which is partially included in a marine protected area and is an important area for biodiversity, is mainly colonised by *P. oceanica* and *Cymodocea nodosa*. This gulf is also vulnerable to both natural and anthropogenic threats. The main human activities in the Gulf include fishing, shellfish farming, and other economic activities related to the production of local specialties like *bottarga*. Fish cages for breeding sea bass and shellfish are present in the northern part of the gulf. The Gulf, especially the northern region, also faces significant tourist pressure due to its beaches, its rich biodiversity, and landscapes.

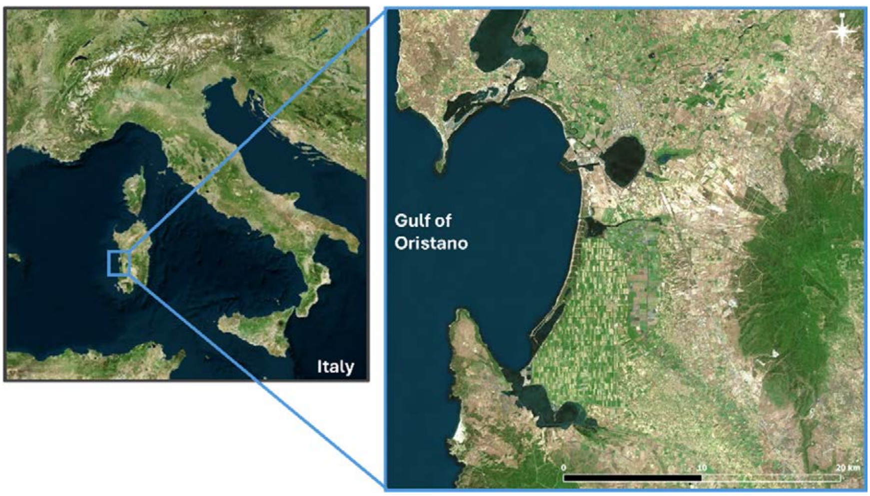

Figure 1 – Map of the location of the Gulf of Oristano (source: *Bing satellite*).

An equivalent methodology is required to process both multispectral and hyperspectral images collected from May to October 2022 (Table 1).

Table 1 – Dates of acquisition of PRISMA and Sentinel-2 images and atmospheric correctors used in the analysis.

PRISMA		Sentinel-2	
24/05/2022	ACOLITE+deglint	23/05/2022	ACOLITE
04/10/2022	L2D	17/06/2022	ACOLITE
		23/07/2022	ACOLITE
		24/08/2022	ACOLITE
		13/09/2022	ACOLITE
		23/10/2022	ACOLITE

The Remote Sensing Reflectance images, downloaded as Level 2 or as Level 1C atmospherically corrected with the ACOLITE code and validated with spectral ground truth, were processed with the BOMBER bio-optical model [9], parameterised with specific inherent optical properties (SIOPs) collected *in situ*, to retrieve the bottom coverage maps of the Gulf of Oristano, based on the dominant spectral signatures. Three classes were identified: *P. oceanica*, Mixed organic and Sand. The parameterisation of the BOMBER code used to process satellite images over the Gulf of Oristano area is shown in the graphs in Figure 2.

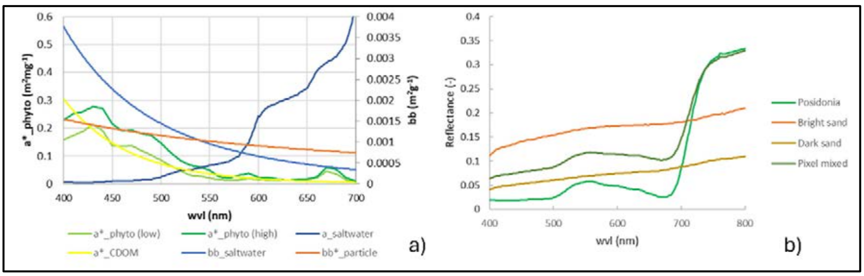

Figure 2 – (a) SIOPs of Oristano water used in the bio-optical model BOMBER code. *a_saltwater* is the absorption coefficient of pure sea water, *a*_phyto* is the chlorophyll-specific absorption coefficient of phytoplankton in two different conditions (low and high presence of phytoplankton measured for the Gulf of Oristano waters), *a*_CDOM* is the specific absorption coefficient of coloured dissolved organic matter, *bb_saltwater* is the backscattering coefficient of pure sea water and *bb*_particle* is the specific backscattering coefficient of particle matter. (b) Spectral signatures of different substrates measured *in situ* in the Gulf of Oristano site.

A field campaign was carried out from 15th to 17th September 2022. Measurements of water reflectance (Rrs) in different regions of the northern part of the gulf (e.g. shallow and deep water, water with different levels of turbidity) were made with different spectroradiometers (i.e., spectral evolution rs-3500; WISP-3). Fluorimetric, turbidity and backscattering measurements were collected at different vertical water depths. At each station, water was collected for laboratory measurements of optically active parameters such as Chl-a, SPM, Coloured Dissolved Organic Matter (CDOM) and absorption properties of phytoplankton and non-algal particles in the visible wavelength range. In addition, data on surface temperature, transparency and bottom depth were collected at each station. For the shallow water areas, spectral signatures of the seagrass (Posidonia, Cymodocea) and the sand dominated bottom were also collected for a total of 61 measures. Other measurements were collected in 5 deep water sites.

As PRISMA cloud-free images were only available on 24th May and 4th October 2022, information on the spatial-temporal variability of water quality parameters was retrieved from Sentinel-2 data to support the reliability of the overall accuracy between *in situ* and modelled data. For Sentinel-2 images BOMBER code was also used to retrieve SPM and Chl-a concentration maps in the six dates analysed (Table 1). Synthetic maps of the coefficient of variation (CV) for the two water quality parameters were produced from the Sentinel-2 derived products, which are useful for identifying spatial-temporal variability of Chl-a and SPM.

Results and Discussion

To analyse the spatial-temporal variability of Chl-a and SPM in the northern part of the Gulf of Oristano, water quality maps were generated from the six Sentinel-2 images for the period May-October 2022. In general, mean Chl-a and SPM concentrations in the months studied were below 1.7 mg m^{-3} and 1.8 g m^{-3}, respectively (Figure 3), with higher values measured near the coastline at the inflow of tributaries or lagoons and in shallow areas where Posidonia can be disturbed by sediment resuspension. The coefficient of variation (CV) maps of the northern part of the Gulf of Oristano for Chl-a and SPM shown a mean value of 0.22 ± 0.08 and 0.37 ± 0.10, respectively (Figure 4). Such results promise stable optical water properties for the Oristano study area in the period May-October 2022, which includes the two PRISMA image acquisitions and the *in situ* data characterisation. The results of the seafloor substrate characterisation obtained with PRISMA are supported by the low variability of the optical water properties of the study area.

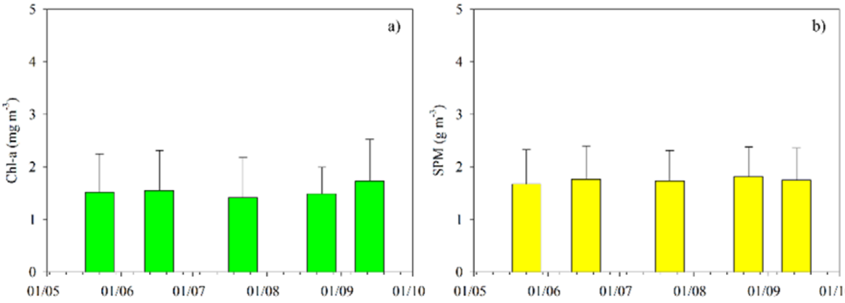

Figure 3 – Mean and standard deviation of chlorophyll-a (Chl-a) (a) and suspended particulate matter (SPM) (b) in the northern part of the Gulf of Oristano from Sentinel-2 images for the period from May to October 2022.

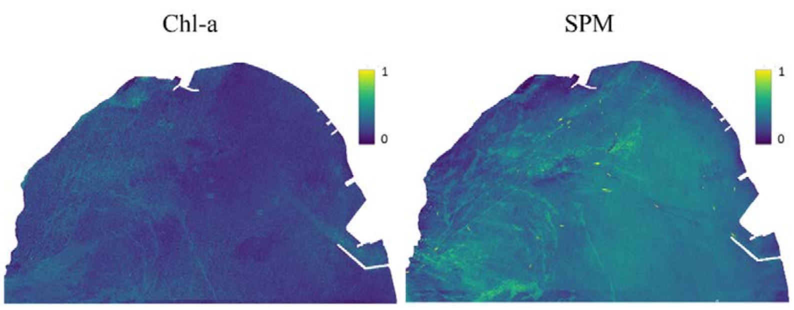

Figure 4 – Maps of the coefficient of variation of Chl-a and SPM concentration derived from Sentinel-2 data for the period May-October 2022.

The confusion matrices for the two PRISMA products (24/05 and 04/10/2022) are shown in Table 2. A good overall accuracy was found for both outputs of the bio-optical model BOMBER, corresponding to 92.4% and 89.4% on May and October 2022, respectively.

Table 2 – Confusion matrices for PRISMA outputs on 24 May and 04 October 2022.

		PRISMA-Bomber 24 May 2022				
		Posidonia	Sand	Mixed organic	Deep Water	TOT
in situ	*Posidonia*	26		2		28
	Sand		27	1		28
	Mixed organic	1	1	3		5
	Deep Water				5	5
	TOT	27	28	6	5	66
				Overall Accuracy		**92.4 %**

		PRISMA-Bomber 04 October 2022				
		Posidonia	Sand	Mixed organic	Deep Water	TOT
in situ	*Posidonia*	25		3		28
	Sand		24	4		28
	Mixed organic			5		5
	Deep Water				5	5
	TOT	25	24	12	5	66
				Overall Accuracy		**89.4 %**

The substrate and canopy coverage products obtained for the northern part of the Gulf of Oristano from PRISMA imagery are shown in Figure 5. The *P. oceanica* coverage (in percentage) is reported for 24th May and 4th October 2022. Looking at the spatial distribution of the seagrass bed in the northern part of the gulf, it is clear that this part of the gulf is widely and densely (>50 %) colonised by the seagrass bed. This condition is particularly evident in May during the growing season and around the time of peak biomass. The seagrass bed was less dense in the October map. In fact, two areas, (a) and (b) in Figure 5, were identified with higher variation in Posidonia cover, where the seagrass cover decreased by about 40 %, moving from the >50 % cover class to the <30 % cover class.

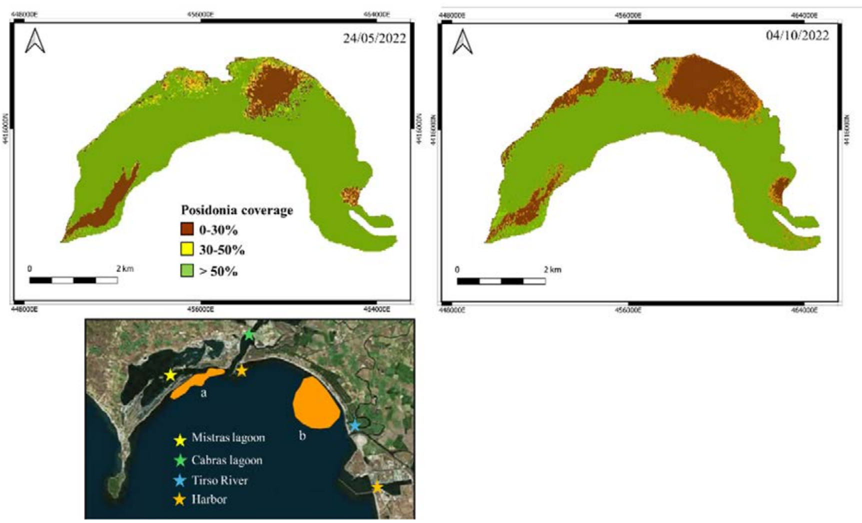

Figure 5 – Maps of the substrate coverage (percentage of *P. oceanica*) on 24th May (upper left) and 4th October 2022 (upper right) for the northern portions of the Gulf of Oristano from PRISMA images. In orange areas of higher variation in the percentage of coverage of Posidonia between the two dates.

In open, undisturbed waters, seagrass beds mainly form dense beds, probably due to the easier establishment of both *P. oceanica* and *C. nodosa* in calm areas sheltered from currents. The substrate cover maps also show four areas with lower *P. oceanica* cover (<30 % or <50 %), mainly covered by sand and/or mixed organic substrate. The area of exchange with the lagoons of Mistras and Cabras has a low presence of seagrass beds due to the supply of nutrients and variations in currents. Even the areas with substrates characterised by the presence of a Paleocosta are not colonised by Posidonia (south-western part of the maps, Figure 5). The coastal area characterised by urban beaches showed a lower cover of Posidonia, probably due to human recreational activities and shipping for fish farming. Furthermore, the map difference between the percentage cover of Posidonia in May and October showed that two areas (in orange in Figure 5) that were highly covered by *P. oceanica* in spring (>50 %) decreased sharply in autumn, with cover percentages of less than 30 %. This may be due to the onset of senescence, but also to the disturbance of the coastal area during the summer season by tourism, shipping, which favours sediment resuspension, and to changes in nutrient inputs from tributaries and the lagoon flowing into the Gulf of Oristano.

Conclusion

The use of hyperspectral PRISMA imagery has allowed the characterisation of the seabed substrate cover in different seasons. This study also demonstrates that the same analytical technique can be successfully applied to different temporal acquisitions when specific optical characteristics of the study area are well defined, with the possibility of minimising *in situ* measurements. Physically based methods for retrieving seafloor parameters are repeatable, allowing the researchers to perform a retrospective analysis showing the spatial distribution of *P. oceanica*. These results were then disseminated to end-users to provide information for the proper management of the Gulf of Oristano area and coastline, considering the multiple interests which are concentrated in this marine area.

Acknowledgements

The study is developed in the framework of the PRISMA SCIENZA OVERSEE project (Contract ASI N. 2022-14-U.0- Call for research "PRISMA SCIENCE" DC-UOT-2019-061).

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EMPOWERING STUDENT ENGAGEMENT AND ENVIRONMENTAL UNDERSTANDING: THE COASTAL HEALTH MONITORING SCHEME (CHMS) IN THE BALEARIC ISLANDS, SPAIN

Samuel Pinya, Sergi Guasch-Martínez, Joan Gil-Perelló, Laia Brunet-Coll, Alejandro Borrás, Guillem Mateu-Vicens, Pere Ferriol, Llorenç Gil, Sílvia Tejada, Antoni Sureda

Abstract: A partnership between the Iberostar Foundation and the University of the Balearic Islands (Spain) through the Chair of the Sea, Coastal Health Monitoring Scheme has a dual purpose: training students in marine biodiversity monitoring and collecting critical coastal ecosystem data. Launched in 2021 on Ibiza with 12 stations, it now boasts 50 stations: 20 in Mallorca, 15 in Menorca, 10 in Ibiza, and 5 in Formentera. Undergraduate Biology students from the University of the Balearic Islands conduct this project. Each station undergoes comprehensive surveys in spring and summer, including three 60 m^2 transects to quantify species density, focusing on sea urchins, sponges, sea cucumbers, and anemones. Population structure analysis is performed by measuring diameters of sea urchins and anemones. Variable-length transects assess benthic species like sea snails and limpets, while others study crab species diversity and Blennoidea fish abundance. Data collected forms a comprehensive biodiversity inventory, enhanced by submerged sand samples to measure organic content and granulometric composition. The CHMS's success is supported by the Iberostar Fdn., Baleària Fdn., local councils, and Island Councils, aiding in transportation, accommodation, and mobility. This collaborative approach enriches marine biology education and contributes valuable insights into coastal ecosystems.

Keywords: Biodiversity, Monitoring Coastal Ecosystems, Coastal Health, Student empowering

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

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Introduction

In higher education, motivating and engaging students in projects with practical social value is a challenge for universities. Nowadays, students can actively participate in research projects initiated by their professors. While this participation is seen as valuable formative activity, it is important to emphasize that its primary purpose is to contribute to the successful execution of the specific research projects, rather than being the core focus of their educational journey.

The Coastal Health Monitoring Scheme (CMHS) serves as a prime example of this educational approach. This initiative is the result of a collaborative partnership between the Iberostar Foundation and the University of the Balearic Islands, made possible through the Chair of the Sea. The project is distinctive in that it has a dual purpose; first, it provides a significant training platform for students, enabling them to gain practical experience in monitoring marine biodiversity. Second, it plays a crucial role in collecting essential data related to the health of coastal ecosystems. This is achieved through the utilization of bioindicator species and the measurement of specific physicochemical parameters.

The origins of this projects can be traced back to 2021 when it was launched as a pilot test on the island of Ibiza, involving the setup of 12 monitoring stations.

The effective execution of this extensive project is achieved with undergraduate Biology students at the University of the Balearic Islands.

This collaborative and integrated approach not only contributes to valuable insights into the health of coastal ecosystems but also provides a unique educational opportunity for students pursuing marine biology. By bringing together multiple stakeholders and actively involving dedicated students, the CHMS exemplifies how practical engagement, and research can lead to a deeper understanding of our natural environment.

Materials and Methods

The network of 50 monitoring stations has been established, with distribution as follows: 20 stations in Mallorca, 15 in Menorca, 10 in Ibiza, and 5 in Formentera (Figure 1).

Each campaign starts with a training day of learning all the methodologies that encompasses the whole Coastal Health Monitoring Scheme, together with the way the information is recorded and written down in each type of datasheet.

Each monitoring station becomes the focal point for a comprehensive set of surveys conducted during the spring and summer seasons.

The data collection process involves the meticulous execution of three transects of 60 m2. These transects play a vital role in quantifying the number of each zoological group, with a particular focus on sea urchins (*Paracentrotus lividus* and *Arbacia lixula*), sponges (*Sarcotragus spinosulus* and *Sarcotragus fasciculatus*), sea cucumbers (*Holothuria tubulosa* and *Holothuria sanctori*), and anemones (*Anemonia sulcata* and *Aiptasia mutabilis*) (Figure 2). Furthermore, the study extends to population structure analysis, which is facilitated by the measurement of the diameter of sea urchins and the basal diameter of anemones.

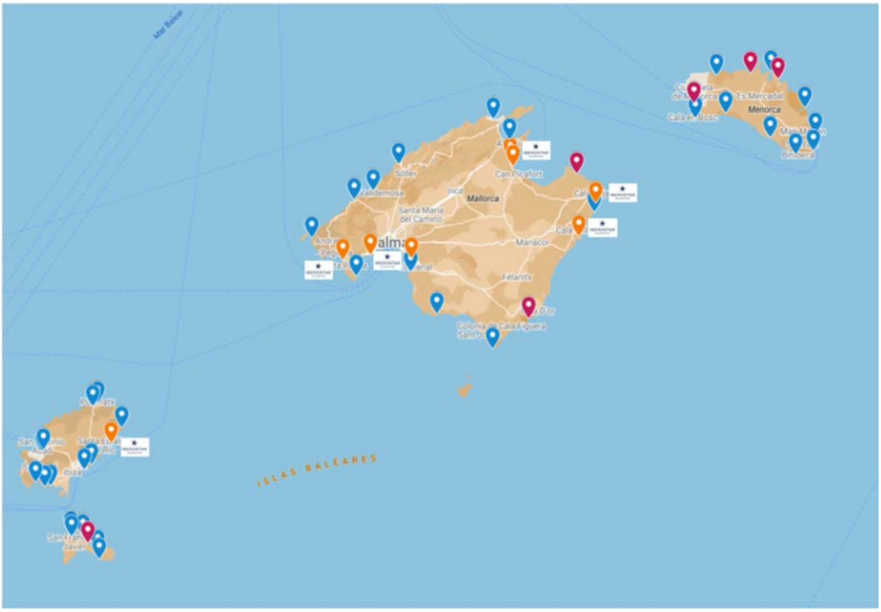

Figure 1 – Distribution of the stations of the Coastal Health Monitoring Scheme at the Balearic Islands.

Additionally, variable-length transects are utilized to quantify the abundance and population structure of another group of benthic species, such as sea snails (*Phorcus turbinatus*) and limpets (*Patella rustica* and *P. caerulea*). Other transects are conducted to assess the diversity and abundant of 11 crab species highlighting (*Pachygrapsus marmoratus*, *Eriphia verrucosa* or *Percnon gibbesi*). Complementarily, a specific inventory and abundance estimation are carried out for Blennoidea fishes. Finally, a global registration of biodiversity of the station is recorded indicating just presence or absence of a pre-established list of species. This way a recorded dataset that effectively serves as a comprehensive biodiversity inventory.

To further augment of value of the data collected, submerged sand samples are diligently gathered. These samples are integral in quantifying the organic matter content and granulometric composition of the sand.

Results and discussion

Since its beginning in 2021 the Coastal Health Monitoring Scheme has allowed the participation to a group of close to 45 different students, some of them repeated up to three times during the summer campaigns (Figure 3).

Figure 2 – Coastal rocky habitat in the Balearic Islands, showing the typical conditions under which the three 60 m² transects are established for biodiversity monitoring.

The massive amount of information has been partially presented in local science meetings such as the VIII Jornades de Medi Ambient de les Illes Balears in up to seven different communications about sea cucumber monitoring[1], anemone monitoring[2], sea crab[s3], sea urchins[4], sea snails and limpets[5], sponges[6] or fish diversity[7]. All these communications about the Coastal Health Monitoring Scheme partial results led to be recognized this monitoring program as a Biodibal students prize ant the VIII Jornades de Medi Ambient de les Balears.

The experience in creating and implementing the CHMS in the Balearic Islands has allowed to improve the early monitoring in the pilot of 2021, emphasizing those techniques where students had more difficulties to develop. Although for a trained scientific it can be easy to follow a protocol or just to handle a specimen for a student is not that easy, so specific training must be followed to succeed in the fieldwork record of information.

First year of the CHMS bring with it some mistakes during the field sheet filling that quickly were corrected for next field days. One of the most challenging issues for CHMS coordination was to keep the concentration for the whole duration of each island campaign.

Figure 3 – Some students and principal researcher participating in the Coastal Health Monitoring Scheme, during a reception at Ibersotar Santa Eulalia Ibiza hotel.

Acknowledgements

The successful implementation of the CHMS is made possible through the support of the Iberostar Foundation, the Baleària Foundation, the local councils of Calvià and Capdepera and Consell Insular d'Eivissa and Consell Insular de Menorca (Menorca - Reserva de la Biosfera). Their contributions extend to essential aspects such as inter-island transportation, logistical support for accommodation and team mobility on each island. Databases were created within the framework of the agreement between the University of the Balearic Islands and Red Eléctrica de España through the Biodibal project.

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OBJECTIVE QUANTITATIVE PARAMETERS TO EVALUATE REPRODUCTIVE ACTIVITY IN *ENGRAULIS ENCRASICOLUS L.*

Rahmani Amina, Iguer-Ouada Mokrane

Abstract: This study focused on novel histological indicators correlated with macroscopic reproductive parameters in male and female European anchovy (*Engraulis encrasicolus*). Weekly sampling from commercial catches in the Gulf of Béjaïa, Algeria, was conducted to measure microscopic parameters, including seminiferous tubule number (STN) and area (STA) in males, and oocyte number (ON) and surface area (OA) in females, independent of maturation stages. Macroscopic reproductive stages were assessed using a standardized five-degree maturity staging system and the gonadosomatic index (GSI). Results showed that OA and ON accurately reflected female maturity stages and exhibited opposing trends with GSI, suggesting their reliability as reproductive activity indicators. Similarly, seminiferous tubules parameters (STN and STA) provided valuable insights into male spermatogenesis and maturation stages. Our findings propose standardized ON/OA and STN/STA measurements as novel, quantitative tools for assessing reproductive activity in anchovy, combining histological and image analysis for a more precise understanding.

Keywords*: Engraulis encrasicolus*, Oogenesis, Spermatogenesis, GSI, Maturity stages.

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Rahmani Amina, Iguer-ouada Mokrane, *Objective quantative parameters to evaluate reproductive activity in* Engraulis encrasicolus L, pp. 288-295, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.26

Introduction

An understanding of the regulation of major biological functions is important for optimizing the reproductive potential of all species, crucial for their survival and sustainability. Reproduction, in particular, plays a vital role in ensuring optimal production in response to various environmental factors. In fish, reproduction is an annual cyclical process that is largely influenced by seasonal variations in the environment [10]. Consequently, knowledge of the spawning season is of great importance. For many years, morphological and histological studies of the gonads have been used to determine reproductive cycles, spawning seasons, and sexual maturity [9]. Macroscopic maturity scales of reproductive organs are commonly used tools for assessing the reproductive status of fish. However, their accuracy may be limited [20]. It is therefore recommended that validation studies be conducted to refine these scales and ensure their accuracy. Histological techniques are widely recognized as powerful tools for studying fish reproduction, offering a precise method for assessing the different phases of reproduction.

Macroscopic studies of gametogenesis are essential for establishing the parameters of reproductive biology. However, microscopy plays an essential role in validating these parameters. Traditional microscopic techniques often remain qualitative and fail to provide objective quantitative data. The advent of advanced digital microscopy and photographic technology has enabled the extraction of meaningful quantitative data from histological images, paving the way for a transition to more quantitative microscopy. This development offers considerable scientific advantages in terms of new applications and data reliability, opening up new avenues for scientific research [12].

The primary objective of this study was to identify quantifiable histological indicators in European anchovy, *Engraulis encrasicolus*, both in males and females. This was done with the aim of understanding and monitoring events related to reproductive activity without the need for fresh samples. Additionally, the study sought to validate new methods for quantifying gonadal histology and to investigate potential correlations with established macroscopic parameters in both sexes, with a particular focus on gametic cell size in males. The ultimate objective was to develop a histological assessment system and tools for studying the reproductive dynamics of anchovy.

Materials and methods

A random sample of anchovy, *E. encrasicolus,* was collected manually on a weekly basis over the course of one year (from October 2007 to October 2008 for males and from January 2010 to January 2011 for females) in order to cover the breeding season. Samples were obtained from the commercial landings of the purse seine fleet at the fishing port of Bejaia (northeast of Algeria) and transported immediately to the laboratory. The gonadosomatic index (GSI) was calculated for each specimen as the ratio of gonad weight to total fish weight, expressed as a percentage in accordance with [11]. Maturity staging was determined according to the following five-point scale [4]: I: Immature stage, II: Developing stage, III:

Spawning capable stage, IV: Regressing stage, V Regenerating stage. The gonads were preserved in 10 % buffered formalin for histological examination, which was conducted in accordance with standard methods. The samples were dehydrated in a graded alcohol series, cleared in xylene, embedded in paraffin, sectioned into 3-4 µm slices, and stained using the Harris Hematoxylin and Eosin (H&E) protocol. The histological sections were photographed at 10x magnification for image analysis. The number of oocytes (ON) and the surface area of the oocytes (OA) were quantified at 10x magnification for females, while the number (STN) and the surface area (STA) of seminiferous tubules were calculated in the same manner for males. The measures of the ON and the STN ware counted in a single microscopic field at 10x magnification. This was carried using UTHSCSA Image Tool 2.0 software (University of Texas Health Science Center, San Antonio, TX, USA). For each female, 250 oocytes were considered, while for each male, 25 seminiferous tubules were considered for the area measurements. The 25 tubules were randomly selected [1] via horizontal scanning, with only those with circular and sub-circular contours were utilized.

The data were analyzed using Statview 5 statistical software (SAS, Cary, NC, USA). One-way analysis of variance ANOVA and Tukey's honestly significant difference (HSD) post-hoc test were used to assess the differences in GSI, OA, ON, STA, and STN between individuals at different stages of sexual maturity, with females and males analyzed separately. Statistical significance was set at $p < 0.05$ for all comparisons. The data were presented as mean ± SE.

Results

A total of 480 anchovy specimens (280 females and 200 males) were randomly collected for this study. The subsequent analyses focused on correlating quantitative histological parameters with established productive indices to assess their efficacy in monitoring gonad development.

In males, seminiferous number (STN, Fig. 1A) and seminiferous area (STA, Fig. 1B) exhibit an inverse correlation with the maturity stages, showing a significant negative correlation between STN and maturity stages ($r = –0.67$, $p < 0.001$) and a significant positive correlation between STA and maturity stages ($r = 0.66$, $p < 0.01$), with the exception of stages IV and V.

Both STN and STA quantitatively express the different maturity stages according to GSI (Fig. 2B), and thus appear as relevant indicators of reproductive activity.

Furthermore, these two parameters demonstrate a negative correlation with each other ($r = –0.88$, $p < 0.001$), and STN (Fig. 1B) evolves in a manner consistent with GSI (Fig. 2B) ($r = 0.68$, $p < 0.001$). The correlation between STA (Fig. 1A) and GSI (Fig. 2B) is $r = –0.61$ ($p < 0.01$), indicating an inverse relationship. GSI (Fig. 3B) exhibited a seasonal pattern, decreasing from October 2007 to January 2008 before increasing to a peak in May 2008.

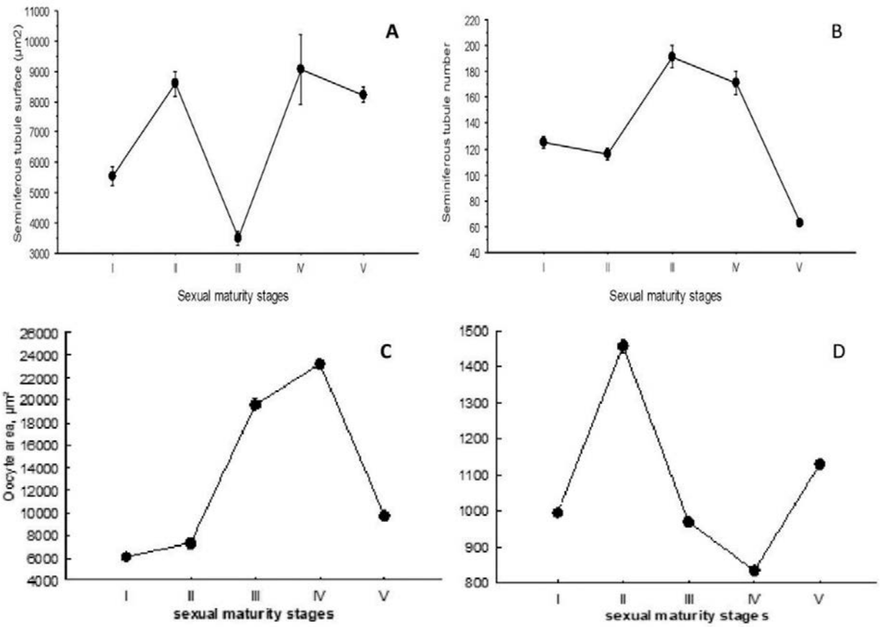

Figure 1 – A) Seminiferous tubules area (µm²), B) Seminiferous tubules number, C) Oocytes surface area (µm²), D) Oocytes number of *E. encrasicolus* at different gonadal maturity stages. Data are represented as mean ± SE.

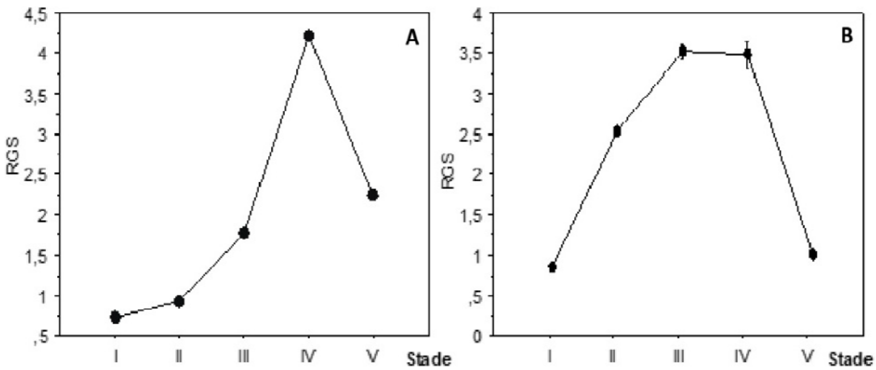

Figure 2 – Gonadosomatic Index percentage (GSI) A) in females and B) in males of *E. encrasicolus* at different gonadal maturity stages. Data are represented as mean ± SE.

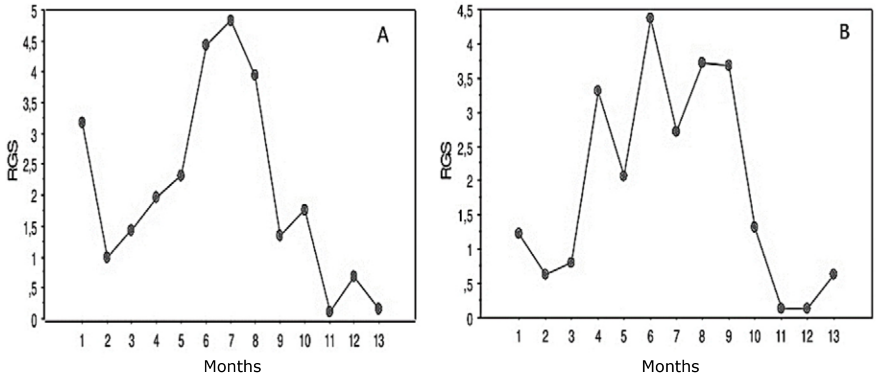

Figure 3 – Gonadosomatic Index percentage (GSI) A) in females (from January 2010 to January 2011) and B) in males (from October 2007 to October 2008) of *E. encrasicolus* collected from Gulf of Béjaïa. Data are represented as mean ± SE.

Similarly, STN and STA (Fig.4 A & B) demonstrated a seasonal changes that mirrored the GSI trend, supporting their potential as monitoring tools. The annual change in cell types occurred from October 2007 to May 2008, with a transition from spermatogonia to spermatozoa via spermatocytes and spermatids over the months, illustrating the maturation process of male reproductive cells.

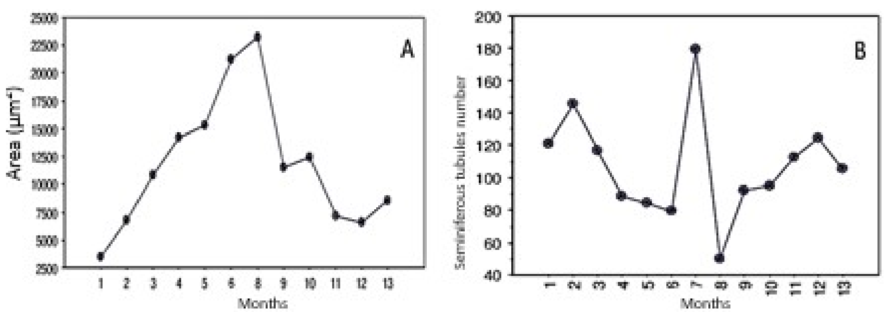

Figure 4 – Monthly variation of: **A**) Seminiferous tubules area (µm²), **B**) Seminiferous tubules number of *E. encrasicolus* collected from Gulf of Béjaïa. Data are represented as mean ± SE.

For females, the maturity stages indicated by ON and OA were found to have evolved simultaneously (Fig. 1A & B), exhibiting similarities with GSI (Fig. 2A), which accurately represented the different development stages. It is noteworthy that OA demonstrated a pattern of parallel development in comparison to GSI, while ON evolved inversely. This suggests that microscopic parameters (OA and

ON) could be valuable as quantitative indicators of anchovy maturity stages. During the research period, GSI increased regularly from January 2010, reaching its maximum values in July 2010. After this, it dropped considerably, reaching its minimum values from November 2010 to January 2011 (Fig. 3A). Similarly, ON and OA demonstrated evident similarities (Fig. 5A & B) with GSI (Fig. 3A) during the same study period. The ON exhibited a similar evolution to GSI from January 2010 to March 2010, followed by an inverse trend at the study period. The OA demonstrated a parallel pattern with GSI.

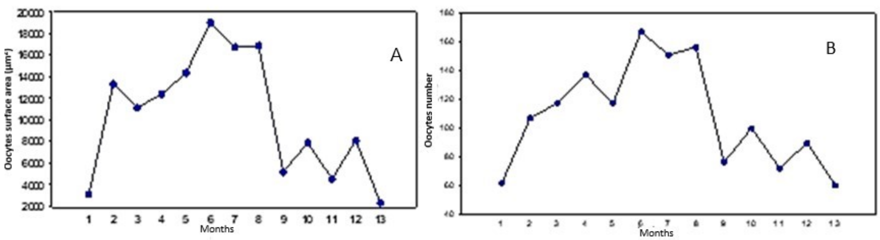

Figure 5 – Monthly variation of: **A**) Oocytes surface area (µm²), **B**) Oocytes number of *E. encrasicolus* collected from Gulf of Béjaïa. Data are represented as mean ± SE

Discussion

While qualitative histological analysis remains a cornerstone for the study of fish reproduction, its limitations become apparent in large-scale studies [13]. Histological techniques although reliable, are known to be time consuming, potentially hindering the efficiency of research involving large sample sizes [5]. Conversely, visual staging based on external gonad appearance offers a faster approach, but its accuracy is often compromised, limiting its suitability for routine studies [7]. Additionally, histological analysis, while providing detailed information on gonadal development stages, requires extensive background research to fully understand the implication of these observations reproductive success at the population level [20].

In that frame, we present a quantitative histological approach to studying male and female anchovy reproduction activity. Our findings demonstrate a significant correlation between the seminiferous tubules and oocytes parameters (STN, STA, ON, OA) and established reproductive indices like GSI and maturity stages. Correlation analysis revealed a strong negative correlation between maturity stages and STN, while a strong positive correlation was observed between maturity stages and STA. In females, an inverse relationship was found, with strong positive correlation between maturity stages and ON, and strong negative correlation with OA. Furthermore, GSI demonstrated a very strong significant positive correlation with STN, and a strong negative correlation with STA. Conversely, GSI showed a strong positive correlation with ON and a strong negative correlation with OA.

The observed decrease in STN and increase in STA during stages I and II is indicative of the presence of larger germ cells (spermatogonia and spermatocytes) lining the tubules. As these cells differentiate into smaller spermatids and spermatozoa, they occupy less space, leading to a reduction in tubule surface area. This inverse relationship between STN and STA indicates the occurrence of intense spermatogenesis, characterized by the transition from stage I, which is devoid of spermatic activity [8], to stages that exhibit active mitosis and early meiotic divisions [6]. Conversely, the inverse evolution of these parameters from stage III onwards reflects spermiogenesis, marked by the abundance of mature spermatozoa [2].

In females, oocyte development follows a distinct pattern. ON and OA increases during oogenesis from stage I to stage IV, reflecting oocyte growth and cytoplasmic heterogeneity culminating in vellogenesis [18]. A subsequent decrease in these two parameters indicates the ovary entering a phase of atresia [3].

The application of quantitative histomorphometry offers a distinct advantage by enabling the application of robust statistical methods to subtle changes in gonadal development. This approach allows for the detection of nuances that might otherwise be overlooked in traditional qualitative analysis. Numerous studies have employed quantitative methodologies to investigate the development of fish gonads [16][17][19].

Conclusion

Our approach diverges from classical oocyte quantification methods, which require categorizing each cell to pre-defined category based on specific criteria. These methods require meticulous histological section preparation to distinguish between germ cell types, particularly in smaller male gonads. Expertise in histological interpretation is crucial for accurate differentiation. The measurement of tubular structures and oocyte, as employed here and detailed in previous articles [14][15], provides a valuable tool for the assessment of gametogenesis and its correlation with physiological functions and environmental parameters.

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THE ROLE OF REBREATHER DIVERS IN THE STUDY OF A MARINE DEEP-WATER CAVE ECOSYSTEM

Vasilis Resaikos, Marios Papageorgiou, Carlos Jimenez

Abstract: This study delves into the diverse marine habitats of Jubilee Shoals, a submerged rocky reef off Pissouri Bay, Cyprus (eastern Mediterranean). The habitats include *Posidonia oceanica* meadows on the plateau, coralline communities on the vertical walls, and a cave system at its base. Utilizing closed-circuit rebreathers, trained cave divers quantitatively described the epibenthic communities and biodiversity within the cave system, ensuring both safety and high-quality data collection. Rebreathers allowed silent, bubble-less operation, efficient gas usage, extended dive times, reduced decompression times essential for detailed observation. The findings underscore the need for rebreathers in scientific exploration of deep-water environments, emphasizing their advantages. This approach facilitates undisturbed marine life observation and minimizes environmental impact, paving the way for future research and conservation in similar ecosystems.

Keywords: Scientific Diving, Marine Caves, Dark Environment, Epibenthic Communities

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Introduction

Submerged caves in the Mediterranean Sea serve as remarkable repositories of information, showcasing unique ecological characteristics. Marine caves have historically intrigued scientists, fostering thus early understanding of these ecosystems. Scientific research has revealed the rich biodiversity found within these caves [1,3].

Within these caves, different sections of the galleries (zones) host distinct species assemblages influenced by gradients of biotic and abiotic factors. Among these factors, the illumination gradient from the exterior to the interior creates unique ecological conditions that support diverse species [7, 4]. Species richness and coverage decrease along this axis [6, 3].

Based on light availability, four zones can be defined: a) cave entrance (CE), b) semi-dark environment (SD), c) dark environment (DE), and d) unspecified environment [8, 3]. Marine cave formations may exhibit a variety of geomorphological features and submersion levels, including fully or partially submerged blind caves, tunnels, and pits, each displaying different degrees of topographical complexity [5].

Rebreathers have a long and complex history in scientific diving, while originally used primarily for military and commercial purposes, rebreathers began to find applications in scientific research with innovations such as Walter Starck's electronically-controlled closed-circuit rebreather (CCR) for undersea biological studies [10]. With the advent of state-of-the-art electronically-controlled, closed-circuit, mixed-gas rebreathers (eCCRs), the capabilities of scientific divers have expanded dramatically, allowing for safer and more efficient exploration of deeper and previously inaccessible marine environments.

Modern eCCR technology addresses many of the limitations of early self-contained underwater breathing apparatus, providing enhanced safety and functionality for underwater researchers [10]. Traditional diving methods using air are safe for shallow short dives, but as depth increases, available bottom time decreases due to decompression obligations, gas consumption, and thermal considerations. Beyond 30 meters, helium-enriched gas mixtures such as trimix are employed to mitigate the narcotic effects of nitrogen and reduce the risk of oxygen toxicity, though these require managing bulky and heavy open-circuit systems with multiple gas cylinders. This rebreathing principle not only enhances mobility and reduces the physical burden on divers but also extends dive durations and depths, making eCCRs an invaluable tool for in-situ scientific research in challenging underwater environments.

We conducted an ecological survey of four marine habitats of the Jubilee Shoals (Cyprus, eastern Mediterranean) between 17÷45 m depth. The use of eCCR was particularly convenient for the evaluation of the epibenthic communities (e.g., photo-quadrats, sediment and plankton samples) and mapping at the deepest areas of the shoals, including inside a cave system. Motivated by the extremely time-efficient survey, we report here the eCCR protocol we followed and the partial results of the evaluation of the epibenthic community (e.g., percentage of cover) inside the cave. We concentrate on the analysis to determine the number of photo-quadrats needed for a proper representation of the species richness in the cave's zones and discuss the advantages that research divers can have using eCCR.

Materials and Methods

The Jubilee Shoals (Petra tis Avdhimou, original toponymy) consists of a submerged rocky reef with a plateau situated 2.4km off Avdhimou Bay (SW coast Cyprus; Fig. 1). The shoals support a complex ecosystem, including three priority habitats recognized by the EU Habitats Directive (Council Directive 92/43/EEC): *Posidonia oceanica* beds at the top, coralligenous on the shoal's walls, and sciaphilic communities within a cave system near the sandy bottom (Fig. 1). The cave system has three entrances between 40÷45 m depth, with an average cave depth of 38 m.

The surveys to evaluate the percent of benthic cover inside the cave were carried out from May to November 2023 by means of eCCR dives (Fig. 2). The cave system was divided into three zones—entrance, semi-dark, and dark—using a bionomic model developed by Pérès [9]. Photo-quadrats (13 cm x 19 cm) to measure benthic cover were taken on the cave walls and ceiling using an Olympus TG-6 underwater camera equipped with a WEEFINE smart focus 5000 light to document the hard substrate epibenthic communities. This compact underwater photographic setup enabled divers to easily navigate narrow passages in the cave to record the system's biodiversity.

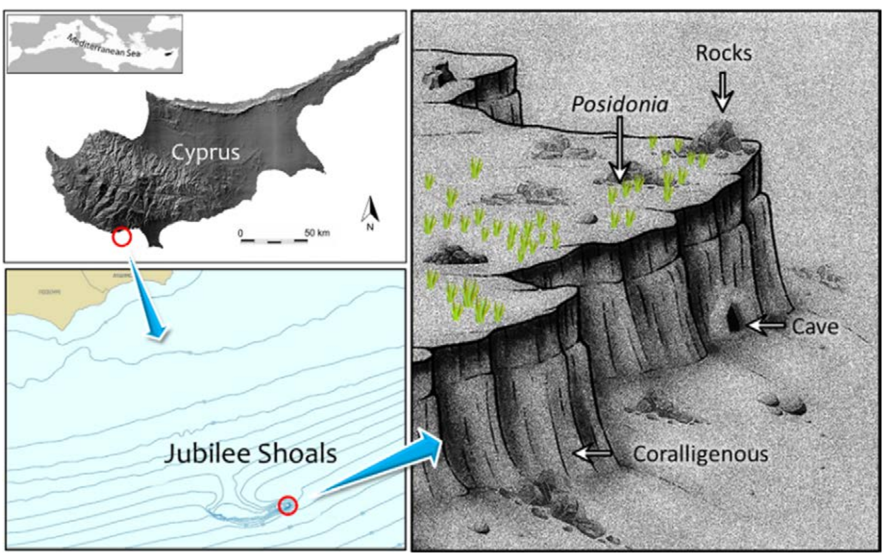

Figure 1 – Jubilee Shoals are located in the SW coast of Cyprus. The rocky outcrop (17÷45 m depth) supports important habitats, such as *Posidonia oceanica* meadows, rocky refs, coralligenous and sciaphilic communities inside and around the cave system.

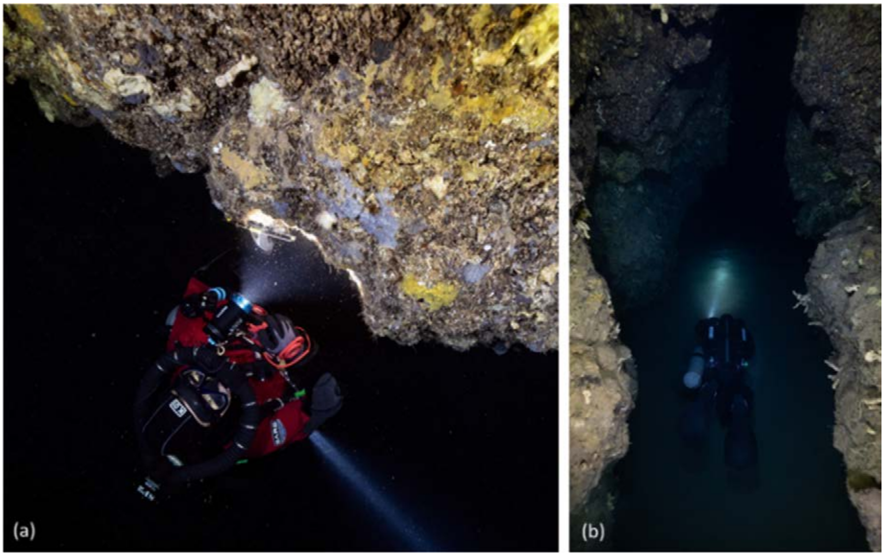

Figure 2 – (a) Epibenthic community on the cave's ceiling surveyed with photo-quadrats (b) Silent and bubble-free surveys of mobile species in the cave's galleries.

At each zone of the cave, 60 replicates (photo-quadrats) were taken from the cave walls (two flanks, 20 replicates each) and ceiling (20 replicates). The PhotoQuad v1.4 software [11] was used for the analysis (N=180 photo-quadrats, 100 points uniform spawn). Additionally, high-resolution macro photos and targeted samples were collected to identify organisms to the lowest possible taxonomic level; organisms whose taxonomy remains to be resolved were assigned to morphospecies. Percentage of cover was classified into seven main categories: Porifera, Cnidaria, Calcareous Algae, Bryozoa, Polychaeta, Others (e.g., Ascidia, Brachiopod, Mollusca, Foraminifera), and non-living Substrate. The R package 'vegan' was used to calculate the Rarefaction curves (version 4.4.1), using random re-sampling of the taxonomic richness of 20 quadrats/zone.

For the eCCR dive calculation and planning, a specialized multi-decompression (multi-deco) program was used. This program, when provided with basic information, such as depth and duration of the dive (among other factors), generates a comprehensive diving plan to ensure safe decompression procedures are followed.

Dive planning Following SSI guide standards

Fixed Parameters: 40 meters Depth, 90 minutes Bottom time, EAD: 30 meters Depth, Limiting ppO2: 1.10, Oxygen in non-narcotic, RMV Bottom: 15, RMV Deco: 17, Setpoint: 1.3, Decompression Model ZHL 16-C + GF, GF: 50/80, Surface interval = 1 day, Elevation = 0 m.

Gas Selection: Step 1: Calculate the oxygen content. Fraction of oxygen (FO2) = Limiting ppO2 / Depth = 1.10/5 bar = 0.22. Step 2: Calculate the nitrogen content: Fraction of nitrogen (FN2) = (Atmospheric partial presser of nitrox * END) / Depth = (0.79 * 4) / 5 = 0.632. Step 3: Calculate the helium content: Fraction of helium = 1- (FO2+ FN2) = 0.148. The best Trimix (TMX): 22/15.

Gas Fraction in the Breathing Loop: Step 1: Calculate the fractions of oxygen in the Breathing Loop: Fractions of oxygen = Setpoint / Depth = 0.26. Step 2 Calculate the fractions of nitrogen in the Breathing Loop: Fractions of nitrogen = [(Depth – Setpoint) * (Nitrogen + Helium)] / Depth = [(5 bar – 1.3) * (62 (%) / 62 (%) + 15 (%))] / 5. Fractions of nitrogen = (3.7 * 0.8) / 5 = 0.592. Step 3: Calculate the fractions of helium in the Breathing Loop. Fractions of helium = 1 – (Fractions of oxygen + Fractions of nitrogen) = 0.148

Equivalent Narcotic Depth (END) = {[FN2 * (Depth + 10)] / 0.79 – 10 = {[0.6 * (40 meters + 10)] / 0.79} – 10 = 27.9 meters

Based on these calculations, a diver can be confident that, when diving to 40 meters with a diluent trimix 22/15 and with a setpoint of 1.3, the actual gas on the loop is trimix 26/15. For logistical reasons, it was not possible to use trimix in this diving operation, so the dives were carried out without trimix. But it is important for this study to show you in detail how to calculate gases under ideal conditions.

Results

Benthic cover

The percentage of benthic cover for each of the seven categories is shown in Figure 3. In general, one category, Porifera, was on average higher than 20 % of benthic cover. Cnidaria (e.g., scleractinian corals), Calcareous Algae and Polychaeta showed noticeable range variations, between 1.7÷35.6 %, 0÷27.1 % and 1.3÷12.1 %, respectively. Bryozoa and Other were consistently low, between 0.2÷11.8 % and 2.1÷15.6 %, respectively. Not surprisingly, the Non-living Substrate was the category with the largest range, between 5.2÷53.5 % of benthic cover. Since the main purpose of this paper is to determine the adequate number of photo-quadrats needed for a good representation of the taxonomic richness from different zones of the Jubilee Shoals' cave, no further analysis was made (e.g., statistical comparison of benthic cover between zones).

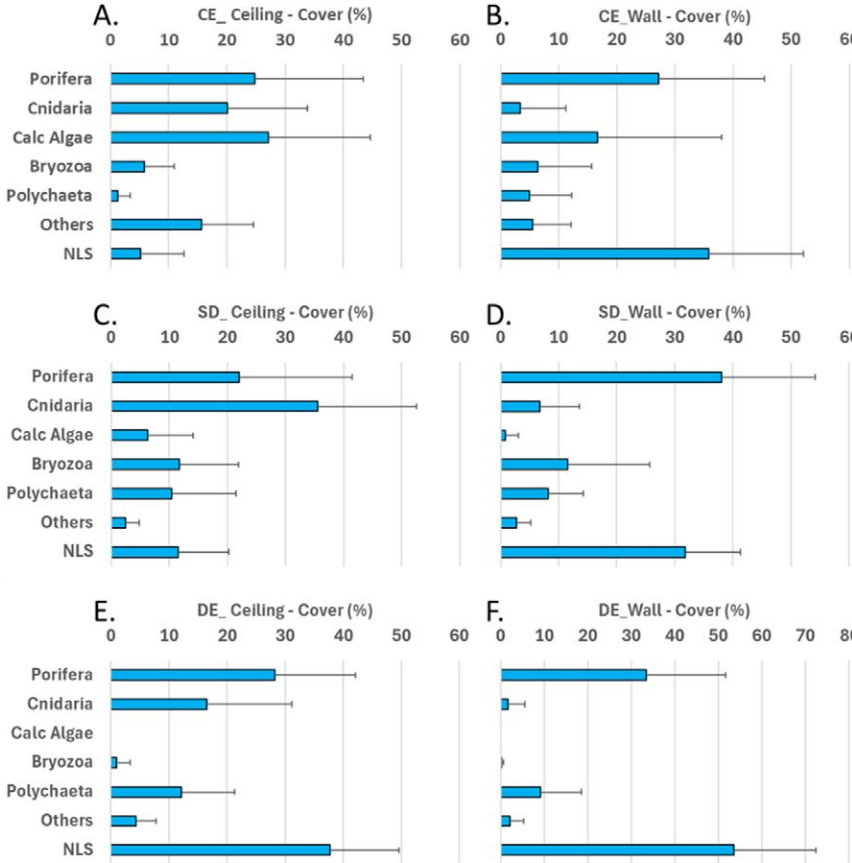

Figure 3 – Percent benthic cover (mean + 1SD; n=20 photo-quadrats) according to seven major categories in different sections of the cave. (A, B) Entrance zone: CE; (C, D) Semi-dark zone: SD; (E, F) Dark zone: DE. NLS stands for Non-living substrate.

The number of species as a function of the number of samples (photo-quadrats) taken, rarefaction curves, are shown in Figure 4. An adequate representation of the number of species, taxonomic richness, is achieved between 11-18 photo-quadrats in most of the cave's zones. The case of the Entrance zone Celling (C, Figure 4A) is different; the results from this zone suggest that more than 20 photo-quadrats are needed for an adequate representation. This is the zone where three categories (Porifera, Cnidaria and Calcareous Algae) are on average higher than 20 % of benthic cover (Figure 3A).

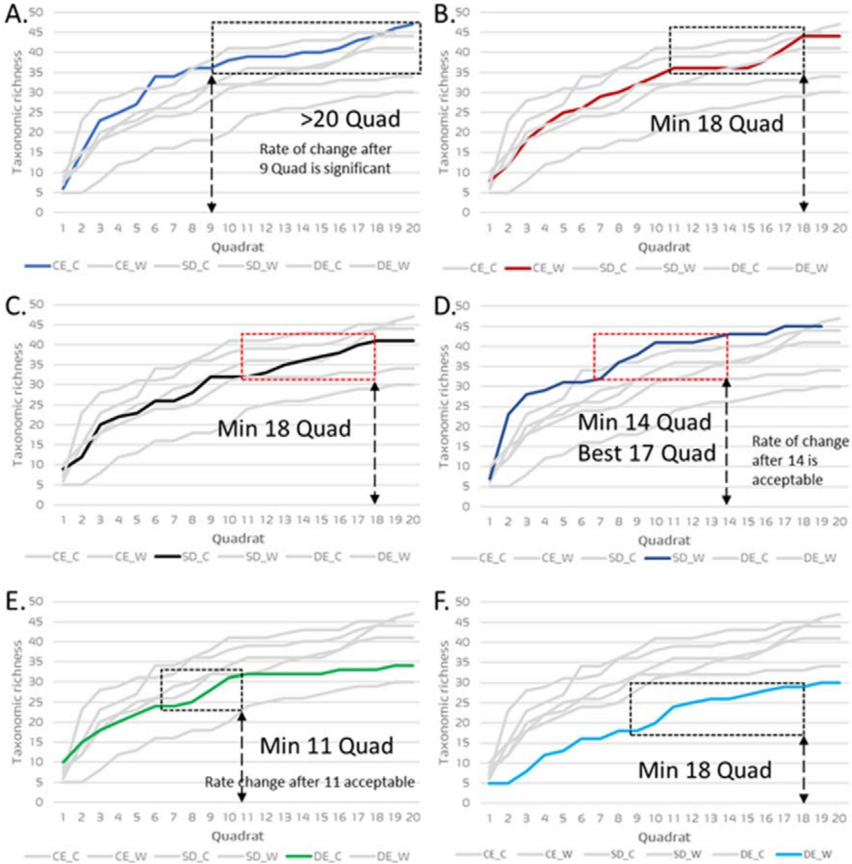

Figure 4 – Rarefaction curves to estimate the expected number of species (taxonomic richness) according to the number of photo-quadrats from different section of the cave: (A, B) Entrance zone: CE; (C, D) Semi-dark zone: SD; (E, F) Dark zone: DE. Rectangles indicate a high rate of change in species number. The suggested number of photo-quadrates necessary for a proper representation is shown with dashed lines and arrows.

Diving plan

By inputting all necessary data into the multi-decompression software, the dive profile was generated (Figure 5). This process also determined the required volume of gas for the dive, applicable to both open circuit and closed-circuit systems (Table 1). It is important to note that the Nitrox 50 and Oxygen used in the Closed Circuit Rebreather (CCR) are designated as bailout gases. This means they are reserved for emergency use and will not be utilized during the dive unless a problem with the CCR arises. Additionally, discussions with experienced closed circuit diving instructors led to the recommendation of different gas mixtures for this dive (Table 2).

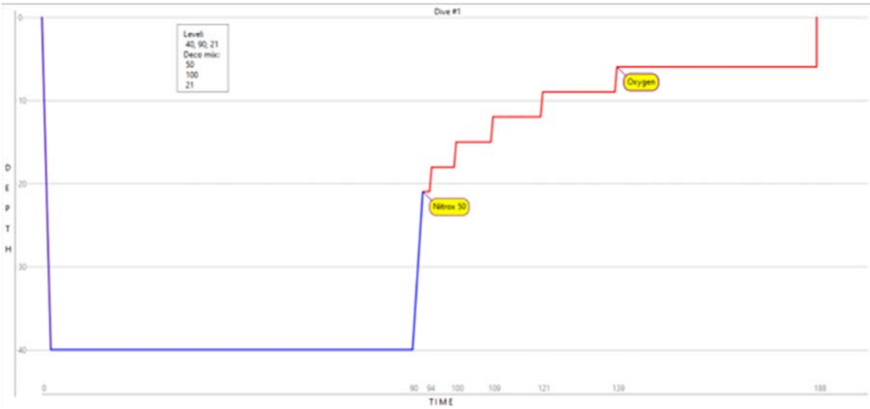

Figure 5 – The diving profile uses atmospheric air (21 %) as diluent.

Table 1 – Gases that will be needed performing the same dive with open circuit: OC and closed circuit: CCR.

	Air (litre)	Nitrox 50 (litre)	Oxygen (litre)
OC	6785.5	1786.1	1337.4
CCR	143.4	1428.4	1174.7

Table 2 – Data generated by multi-decompression software using different diluent.

	Dive time (min)	CNS Total	OTU's this dive	Gas density
OC	189	141.4 %	248	6.0 g/l
CCR	175	143.3 %	261	6.0 g/l
CCR TRIMIX (22/15)	167	139.8 %	251	5.3 g/l
CCR TRIMIX (20/20)	165	139.3 %	250	5.1 g/l
CCR TRIMIX (20/30)	167	142.3 %	252	4.6 g/l
CCR TRIMIX (21/35)	168	145.8 %	255	4.4 g/l

Discussion & Conclusion

The global marine environment has been modified by human activities and climate change with negative consequences, such as loss of biodiversity and disrupted ecological processes. In the Mediterranean, submerged marine caves are considered reservoirs of native biodiversity under the pressure of diverse agents of deterioration [2]. The cave system at the Jubilee Shoals in Cyprus, is an example of an important ecosystem with an almost unknown biodiversity. This study is part of a major effort to document the shoals' habitats biodiversity in order to take actions for their protection and management. However, the conditions to study the cave system are highly demanding because the depth and the restricted environment inside the cave. These factors pose a logistical challenge for the estimation of the benthic cover, particularly when the safety of the scientific divers is unquestionable. The minimum number of samples or photo-quadrats determined in this study, reflects the particular nature of the different zones inside the cave. Only in one case (entrance of the cave) a larger sample number that what was tested in this study is required (more than 20). Nevertheless, determining the sample number is far from being a trivial exercise; more often than not, studies are being conducted without pilot-testing in order to identify the appropriate sample number. It translates into efficiency and effort requirements and logistical aspects (bottom time). This important outcome of the study can be used when deciding the methodology to survey similar environments in other areas.

Up to a depth of 10 meters, open-circuit diving proves more efficient due to its simplicity and practicality. These shallow depths offer extensive bottom times and necessitate relatively modest gas volume requirements. However, challenges arise in buoyancy control and equipment management when employing closed-circuit systems in such environments.

At greater depths exceeding 15÷20 meters, closed-circuit rebreathers offer distinct advantages, notably in extended bottom times. By enabling precise gas mixture regulation tailored to specific depths, these systems minimize nitrogen absorption by the diver's body, thereby substantially reducing decompression obligations. Additionally, the ample gas volume available to the diver enhances both bottom time and operational efficiency. Notably, closed-circuit systems also reduce tank volume and refill frequency requirements, further enhancing operational efficiency.

Nonetheless, a noteworthy drawback of closed-circuit systems lies in their reliance on a 100 % oxygen supply. For dives deeper than 30 meters, helium-enriched gas is recommended, with minimal helium volumes required for depths between 30 and 50 meters compared to the significant advantages it offers, including mitigating nitrogen narcosis and ensuring clearer cognitive function during dives. Furthermore, open-circuit diving generally offers superior breathing quality.

When evaluating the merits and drawbacks of open-circuit versus closed-circuit systems, careful consideration must be given to the specific demands of both dives and equipment provisioning at the chosen location. Enhanced safety stands as a significant advantage of closed-circuit systems, particularly when utilizing helium-enriched gas, although atmospheric air can also suffice for such dives.

A prevalent concern in project planning involves designs crafted predominantly by scientists employing diving as a research tool, often at the expense of safety considerations. Instances where scientists exceed their diving limits to collect requisite data pose significant safety risks, indicative of a broader knowledge gap in diving theory among scientific practitioners. Such scenarios underscore the necessity for scientists to possess comprehensive theoretical and practical diving expertise to foster trust and ensure safety within diving teams.

Crucially, effective scientific diving missions demand the assignment of two responsible individuals—one overseeing the scientific aspect and the other managing diving operations. A harmonious collaboration between these two roles ensures informed decision-making and maximizes data collection efficacy while upholding stringent safety standards.

Based on the results in Table 2, we conclude that a diluent with less than 30% helium is most suitable for scientific dives at this depth. This choice reduces gas density, which in turn facilitates easier work of breathing, lowers the risk of CO2 buildup, and enhances safety during underwater operations.

Our study addressed the dual requisites of producing quality data of the epibenthic communities while ensuring divers' safety by determining the minimum quantity of samples (photo-quadrats) necessary for a proper representation of the taxonomic richness, and by using an eCCR diving protocol. If known, the minimum quantity of photo-quadrats reduces the sampling effort and the eCCR diving protocol maximizes the divers' bottom time. Both are important contributions of this study that can be applied to similar cave environments assisting in the generation of knowledge of these remarkable ecosystems.

Acknowledgements

We would like to thank the UK Government through Darwing Plus Local program for providing the funds for this study, which is part of the project "Assessing and protecting marine biodiversity (Jubilee Shoals, SBAA Akrotiri, Cyprus)" (project DPL00041 to C.J.); the Sovereign Base Areas of Akrotiri and Dhekelia and the Episkopi Special Area of Conservation for granting permission to work at the shoals. Our thanks to Pantelis Charilaou, Margarita Stavrinide for support and advice; to the lineup of divers Christos Patsalides N, Magda Papatheodoulou, Vassilis Tsiairis, George Oikonomidis, Stephen Theakston from Pissouri Bay Divers and PJ Prinsloo, Nikolas Giannoulakis, Edd Stockdale and Vassilis Tsiairis for the recommended diving gases mentioned in the study. This study is part of the first author MSc. research thesis (University of the Aegean). The funders had no role in this project design, data collection/analysis, writing of the manuscript and its publication.

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EFFECTS OF ABIOTIC (SALINITY) AND BIOTIC (ECTOPARASITE) STRESSORS ON *CORIS JULIS* (LINNAEUS, 1758) IN IBIZA, BALEARIC ISLANDS: A BIOMARKER ANALYSIS

Antoni Sureda, Amanda Cohen-Sánchez, Guillem Mateu-Vicens, Pere Ferriol, LLorenç Gil, Antonio Box, Samuel Pinya, Silvia Tejada

Abstract: Stressful situations include abiotic factors such as exposure to hypersaline waters derived from desalination plants and biotic factors such as infection by new parasites introduced by human activities. The aim was to study the effects of an abiotic factor (salinity) and a biotic factor (ectoparasite) on the small coastal wrasse *Coris julis* (Linnaeus, 1758). Specimens were obtained in three areas of the Island of Ibiza (Balearic Islands): control area, area influenced by the desalination plant and area with high levels of parasite infection. Biomarkers of oxidative stress in the gills, liver and epithelial mucus were analysed, as well as immunological markers in the mucus. The two stress factors induced a differential response, with a greater effect of salinity on the gills and a greater effect of the parasite on the liver and mucus. Innate immunity increased in the mucus of fish under both stressors, and immunoglobulin levels increased only in the presence of parasite. In conclusion, *C. julis* specimens affected by salinity and an ectoparasite respond with an increase in antioxidant and immunological defence mechanisms.

Keywords: Biomarkers, Balearic Islands, Oxidative stress, Immune response

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Antoni Sureda, Amanda Cohen-Sánchez, Guillem Mateu-Vicens, Pere Ferriol, LLorenç Gil, Antonio Box, Samuel Pinya, Silvia Tejada, *Effects of Abiotic (Salinity) and Biotic (Ectoparasite) Stressors on* Coris julis *(Linnaeus, 1758) in Ibiza, Balearic Islands: A Biomarker Analysis*, pp. 307-312, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.28

Introduction

Anthropic activity represents a continuous challenge for species that are constantly subjected to different stress situations [4]. Stressful situations include abiotic factors such as exposure to hypersaline waters derived from desalination plants and biotic factors such as infection by new parasites introduced by human action or an increase in the infectious load favoured by pollution.

In the Balearic Islands, high human pressure associated with tourism, especially in summer, causes an increase in water demand that cannot be met by the natural water reserves and, it must therefore be met through the osmosis industry [9]. Recently, the presence of an ectoparasitic trematode of the genus *Scaphanocephalus* that affects the skin of fish from the wrasse family causing 'black spot disease' has been observed in Ibiza [2]. Any factor that causes stress to organisms induces an activation of the metabolism to face this new situation. This fact translates into an increase in the production of reactive species (ROS) which, in turn, induces the activation of antioxidant defence mechanisms [8].In this sense, to avoid oxidative damage and minimize the effects of ROS, organisms have developed antioxidant defence mechanisms that neutralize excess of ROS and maintains the redox balance while also limiting cell damage. Furthermore, any element exogenous to the body induces an activation of immune defences to protect the body. Therefore, the analysis of biomarkers allows to evaluate the potential effects of different stressors on organisms by determining the same parameters.

Coris julis (Linnaeus, 1758), commonly known as the rainbow wrasse, is part of the Labridae family and is one of the most frequently found wrasses in the Mediterranean Sea. It lives in coastal regions, such as rocky areas and seagrass beds, at depths of up to 50 meters [5]. This species is ideal for research due to its high population and adaptability, its sedentary nature, and feeding habits that allow it to accumulate environmental pollutants.

Altogether, the objective of the present work was to study the effects of an abiotic factor (salinity) and a biotic factor (ectoparasite) on the small coastal wrasse *C. julis*. Specimens were obtained in three areas of the Island of Ibiza (Balearic Islands): control area, area influenced by the desalination plant and area with high levels of parasite infection. Biomarkers of oxidative stress in the gills, liver and epithelial mucus were analyzed, as well as immunological markers in the mucus.

Materials and Methods

A total of 27 fish (N=9 per site) of similar size and weight were caught using line-fishing. The abundance of parasites was visually assessed by counting the observable spots on each fish. Gills and liver samples were collected from all fish, and mucus samples were taken from the epithelium of each fish. The experimental procedures were approved by the Ethics Committee for Animal Experimentation of the University of the Balearic Islands (Ref. 020/06/AEXP).

The activities of the antioxidant enzymes catalase (CAT) and superoxide dismutase (SOD) were measured in liver, gill, and mucus samples, while the phase II detoxification enzyme glutathione S-transferase (GST) was assessed in liver and gill tissues following established methods [8]. Additionally, the activity of the immune enzymes alkaline phosphatase (ALP) and lysozyme, as well as the levels of immunoglobulins, were measured in mucus [2]. Reactive oxygen species (ROS) production was determined in liver and gill homogenates using 2,7-dichlorofluorescin diacetate as an indicator, and malondialdehyde levels were also measured in both tissues using a commercial colorimetric kit [1].

Statistical analyses were evaluated using the statistical software package SPSS 27.0 for Windows® (IBM® SPSS Inc., Chicago, IL, USA). The Shapiro–Wilk test was used to confirm the normality of the data, and the Levene's test was used to verify homogeneity of variance. Statistical differences between groups were analysed using one-way ANOVA followed by the Bonferroni post-hoc test.

Results

A total of 27 fish, 9 from each site and treatment were caught. The average total length of *C. julis* was 12.6 cm ± 0.3 cm, and the average weight was 18.3 g ± 1.1 g. There were no statistically significant differences in size or weight among fish from the different sites. Salinity values were as follows: near the desalination plant had 40.1 ± 0.3 PSU, while the area affected by the parasite and Es Freus (control) had normal values of 38.0 ± 0.1 and 37.9 ± 0.1 PSU, respectively. Regarding skin parasites, none were found in fish from the control and salinity sites, whereas in the area affected by the parasite fish had an average of 14.3 ± 1.9 spots per fish.

The two stress factors induced a differential response, with a greater effect of salinity on the gills and a greater effect of the parasite on the liver and mucus (Figures 1 and 2). In general, an increase in the activities of the antioxidant enzymes, catalase and superoxide dismutase (SOD), and in the production of ROS was observed in the gills of fish affected by salinity, while this increase was greater in the liver in fish affected by the parasite. The activity of the detoxification enzyme, glutathione s-transferase (GST), was increased in both tissues and under the two stressors, while no changes were observed in malondialdehyde (MDA) levels as an indicator of oxidative damage.

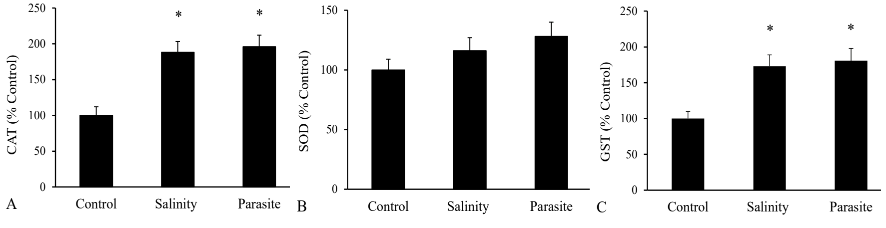

Figure 1 – Activities of (A) catalase (CAT), (B) superoxide dismutase (SOD) and (C) glutathione s-transferase (GST) in the liver of *C. julis*. * Indicates significant differences respect to control, p<0.05.

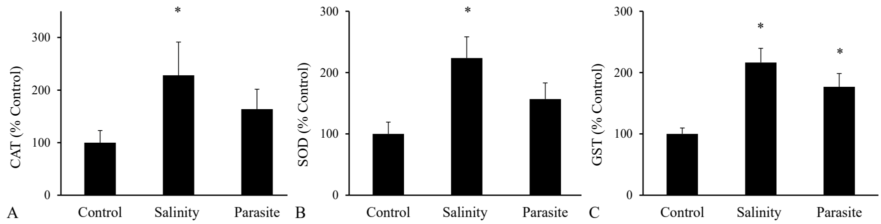

Figure 2 – Activities of (A) catalase (CAT), (B) superoxide dismutase (SOD) and (C) glutathione s-transferase (GST) in the gills of *C. julis*. * Indicates significant differences respect to control, p<0.05.

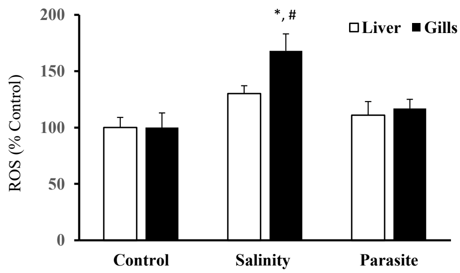

Figure 3 – Reactive oxygen species production in the liver and gills of *C. julis*. * Indicates significant differences respect to control, # Indicates significant differences respect to parasite, p<0.05.

Lysozyme and alkaline phosphatase activity increased in the mucus of fish under the influence of salinity and parasitism, and immunoglobulin levels increased only in the presence of parasite.

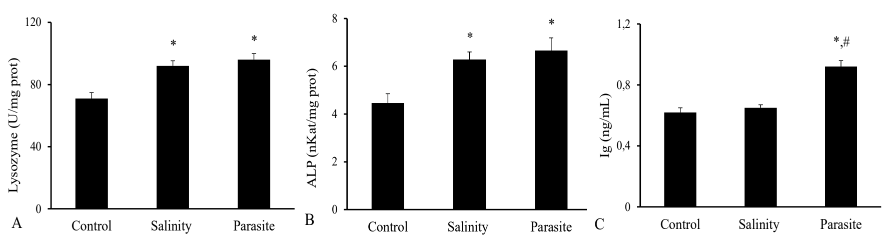

Figure 4 – Activities of (A) Lysozyme, (B) Alkaline phosphatase (ALP) and (C) Immunoglobulin (Ig) levels in the mucus of *C. julis*. * Indicates significant differences respect to control, # Indicates significant differences respect to parasite, p<0.05.

Discussion

The oceans are rapidly changing due to various external and internal factors, impacting the behaviour, life cycles, and internal processes of marine species [7]. One effect of these changes is the production and accumulation of reactive oxygen species (ROS) in exposed organisms. Analysing antioxidant/prooxidant biomarkers can indicate if these changes are causing oxidative stress. This study focused on two major challenges for coastal species in Ibiza Island: high salinity from desalination plant brine discharges and parasite infections.

Ibiza relies heavily on desalinated water due to limited freshwater sources, leading to significant brine discharge into the sea and altering local salinity [9]. Regarding parasites, *Scanocephalus* sp., first identified in Ibiza in 2015, causes black spot disease in wrasse family fish [2]. Initially found in *X. novacula*, it has also been observed in other species such as *C. julis* and *Thalassoma pavo*. The main findings of this study revealed that both stressors induced oxidative stress, primarily affecting the gills in the case of salinity and epithelial mucus with the parasite, along with an immune response. Additionally, the liver, as the main metabolic organ, showed increased oxidative stress markers in fish affected by both salinity and parasites.

Changes in salt concentrations can trigger oxidative stress, as shown by the increased activities of antioxidant enzymes CAT and SOD in *Mytilus galloprovincialis* exposed to high salinity [3]. Our results support these findings, revealing higher activities of antioxidant enzymes and GST, primarily in the gills, which are the tissues most directly exposed to salt stress. Additionally, an increase in liver activities of CAT and GST was observed, likely to meet the demands imposed by the elevated salinity. The increased values of antioxidant enzymes, lysozyme, and ALP in the mucus of fish exposed to salinity indicate a stressful situation. The absence of changes in Ig levels, unlike the response to pathogen infection, suggests a non-specific response to salt stress.

Parasite infection has been found to cause oxidative stress in hosts [6]. The induction of antioxidant enzyme activities in the liver could result from increased metabolic demands due to parasitic infestation, leading to higher oxygen consumption and cellular stress. However, this rise in antioxidant activities helps contain MDA values, preventing oxidative damage. The infection caused a significant increase in lysozyme, ALP, and Ig in the mucus, indicating both an innate and adaptive immune response.

Conclusion

This study highlights the adverse effects of two coastal threats —brine discharge increasing salinity and the presence of the parasite *Scaphanocephalus* sp.— on *C. julis*. The observed antioxidant defence responses to these threats suggest a significant potential risk and stress induction. Additionally, the varying responses across different tissues underscore their sensitivity to environmental changes, demonstrating the value of multi-tissue analysis in identifying early warning signs of various impacts on marine life.

Acknowledgements

This work has been partially sponsored and promoted by the Comunitat Autònoma de les Illes Balears through the Servei de Recerca i Desenvolupament, Direcció General d'Universitats, Recerca i Estudis Artístics and the Conselleria d'Educació i Universitats via Plans complementaris del Pla de Recuperació, Transformació i Resiliència (PRTR-C17-I1) and by the European Union- Next Generation UE (BIO/006). Nevertheless, the views and opinions expressed are solely those of the author or authors, and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission are to be held responsible.

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FISH IMMUNE AND OXIDATIVE STRESS REACTION TO EMERGING PARASITE IN THE BALEARIC ISLANDS

Silvia Tejada, Amanda Cohen-Sánchez, José María Valencia, Antonio Box, Llorenç Gil, Samuel Pinya, Antoni Sureda

Abstract: Global change has a deep impact on the distribution and prevalence of diseases in fish, leading to the emergence of new pathogens. A recent observation on Ibiza Island in the Balearic Islands highlighted the presence of black spot disease linked to a digenean fluke belonging to the genus *Scaphanocephalus* in *Xyrichthys novacula* specimens.
The study aimed at assessing the antioxidant and immune responses in mucus and spleen of *X. novacula*, that are infected by *Scaphanocephalus* sp.
Two sites were selected, one devoid of the parasite and other with its presence. Fish were divided by severity of infection (low or high). Weight and size were measured, and mucus and spleen samples were obtained. As the infection was increased, the body index was worst and antioxidant enzymes activities and immunological parameters in mucus increased. However, the systems could not prevent lipid peroxidation. Also increases in immunological determinations were observed in the spleen.
In conclusion, *Scaphanocephalus* sp. in *X. novacula* triggers an immune response and oxidative stress in the mucus as the infection is more severe. These changes are accompanied by a decrease in their body condition.

Keywords: Ectoparasite; Immune system; Oxidative stress; Pearly razorfish

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Referee List (DOI 10.36253/fup_referee_list)
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Silvia Tejada, Amanda Cohen-Sánchez, José María Valencia, Antonio Box, Llorenç Gil, Samuel Pinya, Antoni Sureda, *Fish immune and oxidative stress reaction to emerging parasite in the balearic islands*, pp. 313-319, DOI: 10.36253/979-12-215-0556-6.29

Introduction

Global change, encompassing factors such as displacement from natural areas, habitat fragmentation, overexploitation, anthropogenic pressure, among others, has a profound and far-reaching impact on the distribution and prevalence of diseases in different animal species, including fish. This dynamic situation is leading to the emergence of new pathogens that can significantly affect the animal who is used as host [12].

A recent observation surrounding the Island of Ibiza in the Balearic Islands (Mediterranean Sea, Spain) has highlighted the presence of black spot disease in specimens of *Xyrichthys novacula* (Linnaeus, 1758), commonly known as pearly razorfish. This disease is linked to a digenean fluke belonging to the genus *Scaphanocephalus* [11]. The presence of the ectoparasite in this fish is particularly concerning given that the pearly razorfish is highly valued as a food source on the islands, suggesting that the presence of this parasite could have substantial impact in social and economic areas [6].

The black spot disease has been described as one of the most common characteristic manifestations of ectoparasite infections [5]. In addition, a rise of the environmental temperature could imply higher reproduction rates of parasites which could accelerate transmission within wild host–parasite systems and increase the overall abundance of the parasites.

In light of these concerns, this study aimed at assessing the antioxidant and immune responses in both mucus and spleen of *X. novacula*, with a specific focus on the extent of infection by *Scaphanocephalus* sp. Understanding these responses is crucial for developing strategies to mitigate the impacts of this emerging health threat on both the fish population and the local economy.

Materials and Methods

The study involved capturing fish in two distinct sandy bottom areas (19 meters depth) in waters of the Ibiza Island (Balearic Islands), the first one was devoid of the parasite and considered as a control site (Sa Mola, Formentera); and another one where the parasite was observed to be present, so as it was considered the infected area (Es Cubells, Ibiza southern) (Figure 1). The animals were captured by hook and line with worms as bait during October 2022.

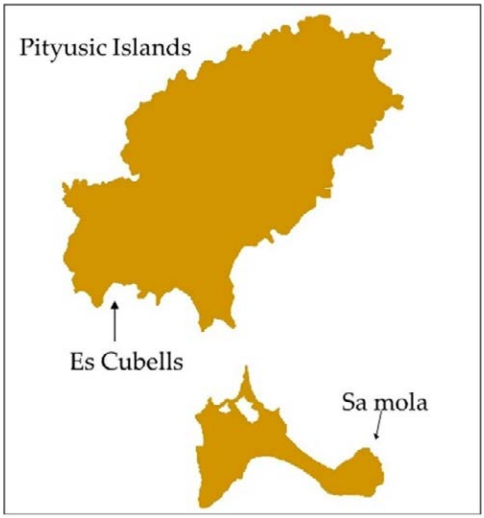

Figure 1 – Sa Mola (control) and Es Cubells (infected) areas where the study was performed.

The spots observed in the fish caught in the infected area were counted, so the animals were classified into two groups based on the severity of infection: low infection (from 1 to 15 spots) and high infection (>15 spots). When the sample size was achieved (10 for controls and 20 for infected, n=10/group), the other captures were returned to the sea.

Under anaesthesia (tricaine methane sulfonate), weight and size were measured for calculate the body index condition [8,9], and mucus and spleen samples were obtained and immediately frozen for posterior analysis. Oxidative stress was evaluated though the measurement of the activities of several enzymes (catalase, superoxide dismutase and glutathione peroxidase) following the procedures described in previous works [1,4,3]. To evaluate if the antioxidant systems protect the organism, the lipidic peroxidation was evaluated by means of measuring the malondialdehyde levels by a colorimetric assay kit following the manufacturer's instructions (Merk KGaA). The immunological parameters were evaluated by spectrophotometry (Shimadzu Corporation) (alkaline phosphatase, myeloperoxidase, lysozyme) or as previously described [7].

Data was analysed by one-way analysis of variance (ANOVA) followed by the Levene test to determine the statistical differences considering $p < 0.05$. Data was also checked for normality of the variance. The statistical package IBM SPSS Statistics software (SPSS) was used for the analysis of the data.

Results

A sample of a specimen of *Xyrichthys novacula* affected by the ectoparasite *Scaphanocephalus* sp is shown in the figure 2.

Figure 2 – Example of *Xyrichtys novacula* infected by *Scaphanocephalus* sp. (genetically identified).

The levels of the antioxidant enzymes in mucus of the *X. novacula* are represented in figure 3. A statistically significant increase was observed in the infected fish for catalase respect the control. For superoxide dismutase and glutathione peroxidase, the rise was significant in the animals with higher infection, when compared to the respective controls.

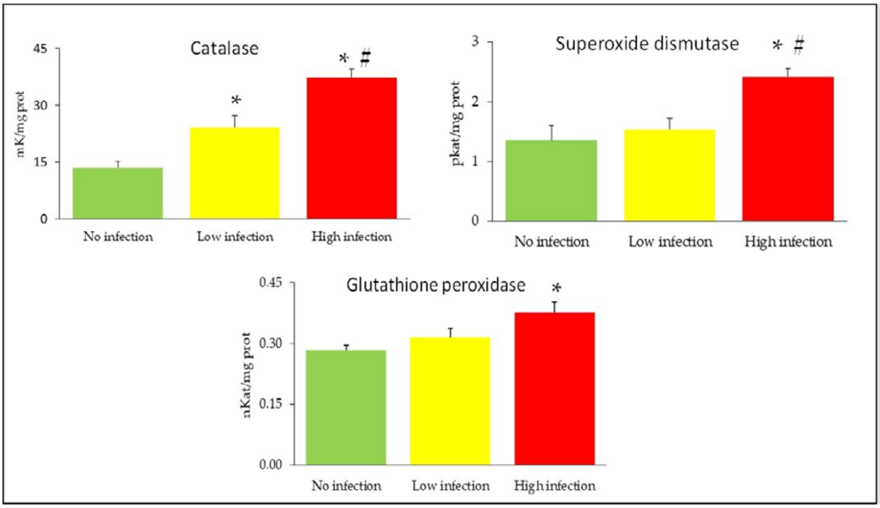

Figure 3 – Antioxidant enzyme response in mucus of razorfish in Sa Mola (control) and Es Cubells (infected). Bars represent mean ± SEM. * *vs* control, # *vs* low infection. One-way ANOVA, $p<0.05$.

The Malondialdehyde (MDA), as a marker of lipidic damage, values in mucus of the *X. novacula* specimens are included in table 1. Those animals with a higher infection (more than 15 spots) showed an elevated MDA values when compared with control and the fish lessen infected (1-15 spots).

Table 1 – Malondialdehyde (MDA) levels (mean ± SEM) in mucus of razorfish in Sa Mola (control) and Es Cubells (infected). * *vs* control, # *vs* low infection. One-way ANOVA, p<0.05.

	MDA (nmol/mg protein)
Control (no infection)	1.76±0.15
Low infection (1-15 spots)	1.82±0.29
High infection (>15 spots)	2.98±0.39*,#

Figure 4 includes the results observed in the immunological variables studied in the mucus and spleen of the razorfish. The rise in the values of the markers study was higher as the infection was more severe.

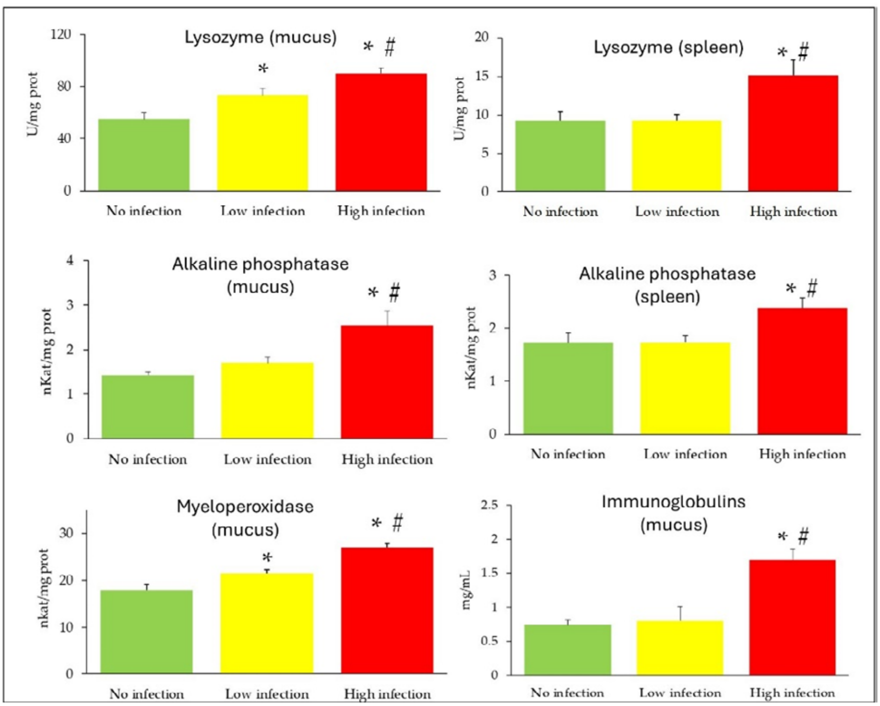

Figure 4 – Immunological parameters in mucus and spleen of razorfish in Sa Mola (control) and Es Cubells (infected). Bars represent mean±SEM. * *vs* control, # *vs* low infection. One-way ANOVA, p<0.05.

Discussion

As the degree of infection increased, a noticeable decline in the body condition index was observed, indicating the detrimental impact of the ectoparasite

Scaphanocephalus sp. One significant finding of this research was the increasing activity of the antioxidant enzymes in the mucus, including catalase, superoxide dismutase, and glutathione peroxidase, as the infection level increased. This increase in antioxidant defences aimed to counteract the oxidative stress imposed by the parasite. This defensive response seems to be partially effective in the fish with fewer spots, correlated with a fewer degree of infection of these animals. However, despite the activity of the antioxidant systems of the fish, the higher infection levels led to an elevation in malondialdehyde concentrations, which indicated lipidic oxidative damage. This rise highlights that the group with the most extensive infection exhibited an overwhelmed state of the antioxidant defenses. These results are consistent with previous research conducted with the same fish species [2,13].

In addition to the antioxidant response, the study also revealed a corresponding increase in various immunological parameters as the infection severity rose. These parameters included lysozyme, alkaline phosphatase, myeloperoxidase, and immunoglobulins. Also, lysozyme and ALP activities in the spleen of the higher infected specimens of *X. novacula* were observed although no differences were showed in the low infection. Similar results have been described in a previous study in which the damage in fish gills infected with an ectoparasite was more severe as the infection increased, affecting both the antioxidant system and the immunological parameters [13]. The study findings underscore the complexity of the immune and antioxidant responses in *X. novacula*, revealing both the capacity and the limits of the fish's defenses against parasitic infection.

Altogether, this immune response was indicative of the fish's attempt to combat the infection by *Scaphanocephalus* sp. This research contributes valuable insights into the broader understanding of how global change and emerging pathogens impact marine life, emphasizing the need for ongoing monitoring and adaptive management strategies to protect vulnerable species and ecosystems.

Conclusion

The presence of *Scaphanocephalus* sp. in *X. novacula* triggers both an immune response and a state of oxidative stress in the mucus as the infection becomes more severe. These changes in the physiology of the fish are accompanied by a decrease in their overall body condition. The potential effects that this ectoparasite can have on affected *X. novacula* populations highlight the need for continued with the studies, and more extensive research to monitor and understand the long-term impact of this infection.

Acknowledgements

This work has been partially sponsored and promoted by the Comunitat Autònoma de les Illes Balears through the Servei de Recerca i Desenvolupament, Direcció General d'Universitats, Recerca i Estudis Artístics and the Conselleria d'Educació i Universitats via Plans complementaris del Pla de Recuperació, Transformació i Resiliència (PRTR-C17-I1) and by the European Union- Next

Generation UE (BIO/006). Nevertheless, the views and opinions expressed are solely those of the author or authors, and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission are to be held responsible. This research was also funded by the Programme of Promotion of Biomedical Research and Health Sciences, Instituto de Salud Carlos III (ISCIII), grant number CIBEROBN CB12/03/30038.

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FLORA AND HABITATS ON ALGIER'S COASTLINE (ALGERIA): STATE OF KNOWLEDGE AND CONSERVATION ISSUES

Nassima Yahi, Sofiane Ahmed-Zaid, Imen Kafi, Nassima Souyad

Abstract: Coastal ecosystems are rich in biodiversity and maintain a delicate ecological balance. They serve to preserve biodiversity, protect against erosion and stabilize sediments. Nevertheless, they are facing major challenges. Coastal dunes in particular are being affected by a combination of human and natural pressures. They require the implementation of sustainable conservation strategies. Algeria's coastline faces a number of threats, including increasing urbanization and summer overcrowding. These factors have led to the degradation of coastal dunes, threatening flora and habitats. Conservation measures are therefore urgently needed. This study contributes to the assessment of some coastal habitats in Algiers through an inventory of the flora and the monitoring of a number of emblematic species. Meanwhile, a diachronic analysis of the flora has been undertaken in order to understand the fluctuations that have occurred over time. This diagnosis of the coastal flora and the major threats to the habitats provides information on their conservation status and serves as a reference for future conservation and restoration studies.

Keywords: Dune vegetation, Coastline, Mediterranean, South shore, Monitoring.

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Introduction

Coastal dunes and lagoons are unique, fragile and dynamic ecosystems located between the sea and the land. These areas play a vital role in the coastal environment, providing a range of ecosystem services and supporting rich biodiversity. Their conservation is essential to preserve these precious habitats and to ensure their ecological functionality [12].

Coastal areas are characterized by a high level of risk because of their intrinsic vulnerability to the sea action and the high number of socio-economic activities such as artificial structures, extraction of dune sands, grazing and hotel constructions. Among coastal habitats, dunes are particularly studied and considered in conservation status assessments, especially in the Mediterranean biogeographical regions, where they represent the most vulnerable habitats in the face of human and natural pressures [1].

Along the coast of Algiers, the dune vegetation has been the subject of few phytoecological-phytosociological [16, 6, 7, 8, 9] and ecophysiological studies [14, 2]. These contribute to a better understanding of plant community structure and plant adaptation strategies to the hostile conditions of coastal dunes.

The aim of the present study is to update our knowledge of the floristic composition of Algerian coastal dunes and to carry out a diachronic analysis of the dune flora in the face of global changes affecting these fragile ecosystems.

Materials and Methods

1. Study area

In the eastern part of the Algerian coast, beaches dominate the coastline and cover most of the area, while cliffs form only a small proportion [14]. In contrast, much of the west coast of Algeria is characterized by low rocky plateaus, cliffs with varying slopes and terraces. The cliffs are interspersed with coves and bays with sand or gravel deposits. Dunes are found in limited quantities at the mouths of the Nador and Mazaffran rivers [9].

The study area is located in the coastal region of Algiers, which extends from Bou-Ismail Bay in the west to Zemmouri Bay in the east for approximately 150 km along the Mediterranean coast. The coastal plains and hills of the Algerian Sahel define the southern boundaries of the area. It is important to note that the scarcity of coastal dunes in this zone required the selection of sites. The first site was to the east of Algiers (Zemmouri) and the second to the west (Zéralda). The choice of these two sites was based on their representativeness and the presence of vegetation relevant to the study (figure 1).

The study area has a sub-humid bioclimate with warm winters. The summer dry season lasts about 4 months (Table 1).

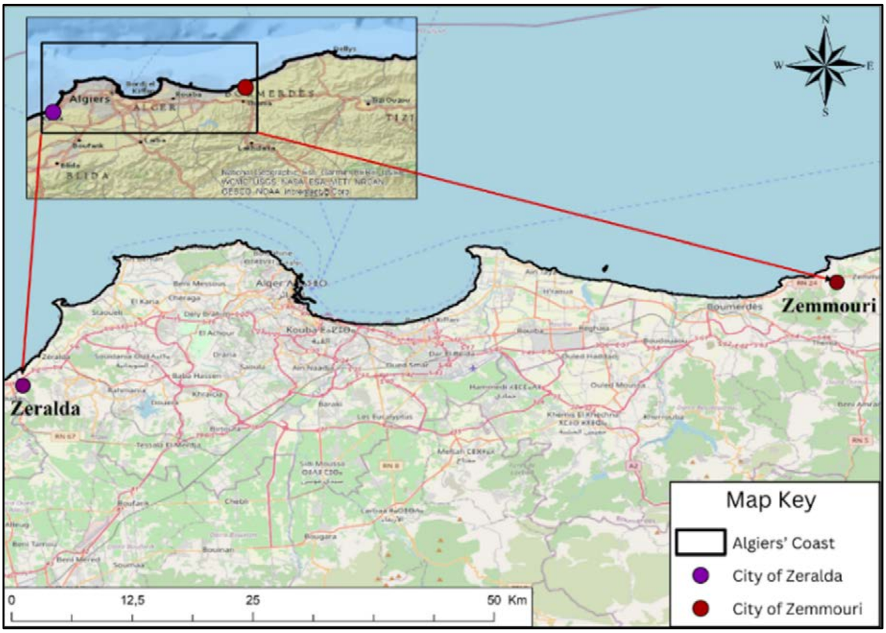

Figure 1 – Study area.

Table 1 – Climate summary for the Zemmouri and Zéralda regions for the period 1991- 2021 (Climate data, 2021).

City	Annual precipitation (mm)	Average annual temperature (°C)	M (°C)	m (°C)	Dry period	Bioclimate
Zemmouri	672	17.5	32.8	5.6	From mid-May to mid-September	Subhumid with a warm winter
Zeralda	605	18.3	30.2	8.7		

2. Vegetation sampling and analysis

Vegetation sampling was carried out in a subjective mode. Plots were selected on the basis of their homogeneity and ability to represent dune vegetation. In the first phase, transects were made in the presence areas with systematic measurements. The results of this phase are not included in this study. Subsequently, 26 floristic surveys were carried out using the sigmatist (phytosociological) method [6]. The taxa have been identified using the flora of Quezel et Santa [13]. The nomenclatural update was made on the basis of the synonymic index of Dobignard et Chatelain [4].

The content of our surveys is compared with those carried out at Zeralda and Zemmouri by other authors in 1960 [16] and 2008 [7,8,9] to support our diachronic analysis of the coastal dune flora.

Floristic surveys were analysed using R. The results were presented by means of a factorial correspondence analysis, which enabled several plant groupings to be identified. These groupings are characterized on three different levels: physiognomic, biological and phytogeographic.

Station assessments have been used as an approach to provide an overall view of the situation of the study populations. They can be applied to a single taxon, to several taxa, or to a plant community as a whole [10].

To estimate plant diversity of the regions of Zemmouri and Zeralda over three temporal intervals, the Shannon-Weiner index (H'), Simpson's diversity index (D) and Pielou's evenness index were calculated. The equations of these indices are as follow:

$$H' = -\sum[(pi)\times\ln(pi)] \quad (1)$$

where:
H': Shannon-Weiner index;
pi: ni/N (ni: number of individuals of a species, N: total number of species);
ln: natural log.

$$D = 1 - \sum (n/N)^2 \quad (2)$$

where:
D: Simpson's diversity index;
n: number of individuals of a particular species;
N: total number of individuals of all species.

$$E = H'/Hmax \quad (3)$$

where:
E: Evenness index:
H': Shannon-Weiner index;
Hmax: natural logarithm of the total number of species.

To evaluate the similarities between the both regions at different periods of time, Jaccard and Sørensen indices were calculated using the following equations:

$$S_J = a / (a + b + c) \quad (4)$$

where:
S_J: Jaccard index;
a: number of species common to list 1 and 2;
b: number of species specific to list 1;
c: number of species specific to list 2.

$S_S = 2a / (2a + b + c)$ 5

In the previous equation, (S_S) represents the Sørensen similarity index, (a) the number of species common to list 1 and 2, (b) the number of species specific to list 1 and (c) the number of species specific to list 2.

Results

1. Identification and characterisation of plant groups

The results of the multivariate analysis show that axis 1 contrasts two types of vegetation, a woody and shrubby pre-forest in its positive part belonging to the *Ephedro fragili-Pistacietum lentiscii* [5]. In its negative part, low maritime sand vegetation can be distinguished, belonging to the *Otantho maritimi-Ammophiletum australis* [5]. Axis 1 is interpreted as a structural vegetation gradient. Axis 2 contrasts two types of survey. In its positive part, surveys carried out on sites disturbed by human action and in its negative part, surveys carried out on less disturbed embryonic dunes. Axis 2 is interpreted as a gradient of anthropisation.

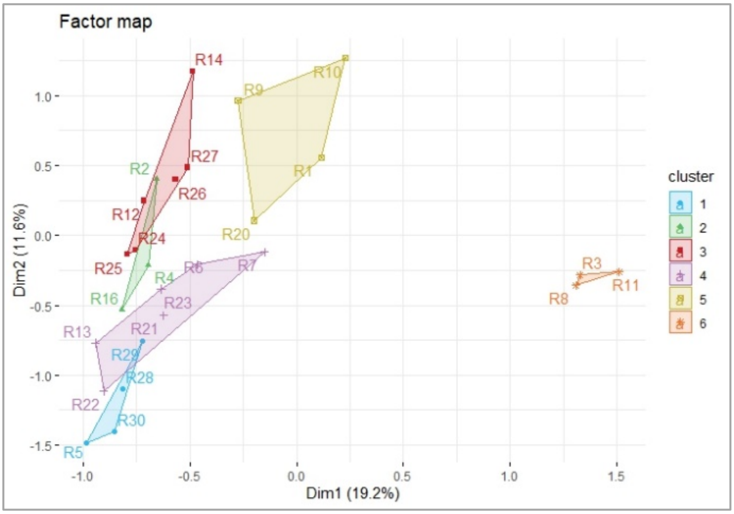

Figure 2 – Factor map of surveys.

G1: Grouping of low vegetation with patches of *Achillea maritima*;

G2: Grouping of low vegetation dominated by *Eryngium maritimum* and *Cakile maritima*. It can be considered as a pioneer grouping of maritime dunes;

G3: Low vegetation grouping dominated by *Pancratium maritimum*. In addition, significant cover values are attributed to associated species such as *Eryngium* *maritimum, Elytrigia juncea, Salsola kali*, which is present at the periphery of the beach, and *Xanthium strumarium,* which is considered an invasive species;

G4: Low vegetation dominated by *Ammophila arenaria*, with a significant presence of *Pancratium maritimum*, *Cakile maritima* and *Lotus creticus*;

G5: *Lotus creticus* and *Echium sabulicola* dominate this low vegetation grouping, with the presence of *Ononis variegata and Centaurea sphaerocephala.*

G6: Pre-forest grouping almost dominated by shrubby species: *Ephedra fragilis, Phillyrea angustifolia, Pistacia lentiscus*. We note the presence of *Quercus coccifera*.

2 Biological characterisation

The dominance of a biological type (real biological spectrum) is directly linked to the physiognomically dominant species. In the low-lying vegetation groups on sea sands, we note the predominance of chamephytes (G1), therophytes (G2), geophytes (G3 and G4) and hemicryptophytes (G5). Cover in grouping 6 is dominated by phanerophytes (91 %), followed by therophytes and hemicryptophytes (3 %), chamaephytes (2 %) and finally geophytes (1 %). This grouping reveals a pre-forest environment marked by the presence of *Ephedra fragilis, Pistacia lentiscus, Phillyrea angustifolia* and *Quercus coccifera*.

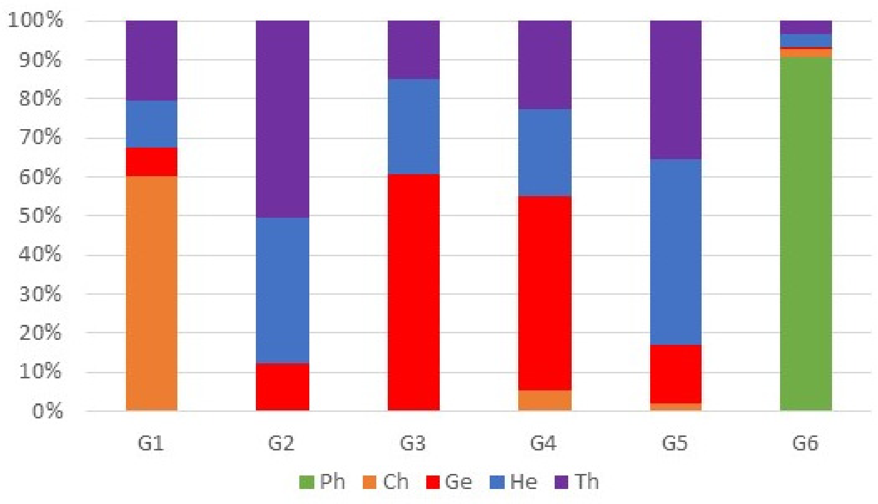

Figure 3 – Biological spectrum (Ph: phanerophytes, Ch: chamaephytes, Ge: geophytes, He: hemicryptophytes, Th: therophytes).

The flora studied shows that the Mediterranean and wide distribution dominate globally in the 6 grouping (Figure 4).

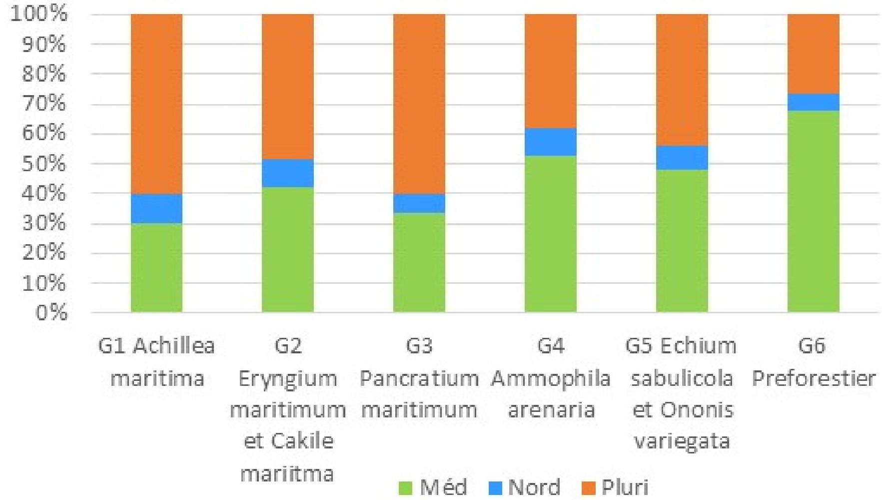

Figure 4 – Biogeographic spectrum.

3. Station assessments

As part of our study, we carried out station assessments for some emblematic species on the coast of Algiers: *Achillea maritima*, *Ammophila arenaria* and *Pancratium maritimum*. The aim was to analyse their chorology and phytoecology, and to identify the main threats facing their populations along the coast.

At the Zéralda site, *Pancratium maritimum* (Figure 5) is threatened mainly by over-visitation during the summer period and sand stripping to build car parks, transport routes and tourist complexes.

At the Zemmouri site, *Ammophila arenaria* (figure 6) is threatened by over-grazing, over-tourism, sand stripping just a few metres from its habitat, pollution and vehicle traffic on the dunes.

Initial monitoring of *Achillea maritima* populations in its potential range at Zemmouri shows that it has not managed to colonise the upper reaches of the beaches and is confined to small patches (Figure 7) scattered on embryonic dunes or at the transition to white dunes. These areas are currently very threatened by the passage of vehicles and heavy machinery. They deserve to be protected.

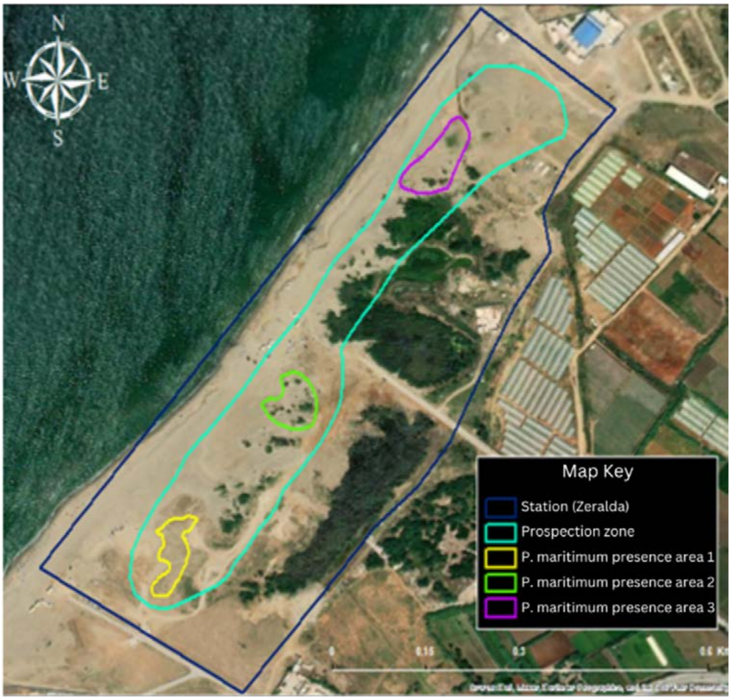

Figure 5 –. Areas of occurrence of *Pancratium maritimum* in the sampled site of Zeralda.

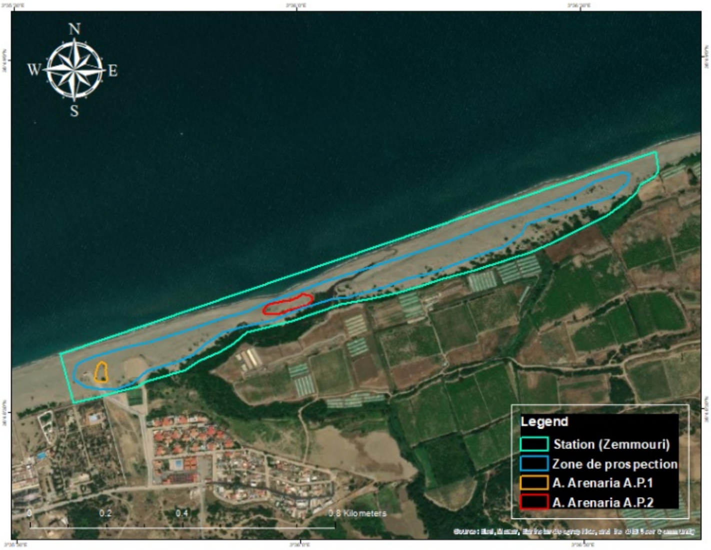

Figure 6 – Areas of occurrence of *Ammophila arenaria* in the sampled site of Zemmouri.

Figure 7 – Areas of occurrence of *Achillea maritima* in the sampled site of Zemmouri

4 Plant biodiversity

The evaluation of alpha diversity in plant communities across two regions of coastal dunes in Algiers and during three periods of time (1960, 2008 and 2023) revealed significant patterns when measured using Shannon-Weiner, Simpson and Pielou indices (Table 2). Overall, the values of Shannon-Weiver index ranged between 1.81 and 2.32, which means that the diversity of these two regions across the three periods of time is moderate. The same observations were made for Simpson's index where the diversity was mainly moderate, while for the Evenness index, it indicated that the two regions across the three periods were generally unstable with some exceptions.

In Zemmouri region, the Shannon index, which measures diversity of species within a community, indicated a moderate stable diversity over time, with values around 2. The Simpson index, which also accounts for species diversity, showed a significant decrease of diversity and this in 2023 compared to the two previous periods (1960 and 2008), where the Simpson index was around 0.65, suggesting a more uneven distribution due to the dominance of a few species. The Pielou's index, reflecting species evenness, corroborated these findings by demonstrating unstable communities across time.

Table 2 – Summary of the values of Shannon, Simpson and Evenness indices in both regions of Zemmouri and Zeralda.

	Shannon index			Simpson index			Evenness index		
	1960	2008	2023	1960	2008	2023	1960	2008	2023
Zemmouri	2.07	2.03	2.08	0.85	0.85	0.65	0.72	0.67	0.65
Zeralda	1.99	2.32	1.81	0.70	0.88	0.78	0.84	0.77	0.62

The second region, Zeralda, displayed an increase in both Shannon and Simpson indices during the period of 2008, and then declined in 2023, reaching the values of 1.81 and 0.88 for Shannon and Simpson indices, respectively. The stability of the dune ecosystems, evaluated by the Evenness index, showed in an important decline in plant community stability in this region between 1960 and 2023.

The analysis of plant composition using Jaccard and Sørensen similarity indices showed significant temporal variations across the three distinct periods in both Zemmouri and Zeralda regions (Table 3). The highest similarity in plant composition was recorded between 2008 and 2023 in the region of Zemmouri, whereas in Zeralda region, it was observed between 1960 and 2008. On the other hand, the lowest similarity was noticed between 1960 and 2023 in Zemmouri region and 2008 and 2023 in Zeralda region.

Table 3 - Summary of similarity indices (in %) between the three periods of time in the regions of Zemmouri and Zeralda.

	Zemmouri		Zeralda	
Pair comparisons	Jaccard	Sørensen	Jaccard	Sørensen
1960/2008	30	46	35	52
1960/2023	25	41	30	47
2008/2023	35	52	25	40

5 Threats Assessment on the dune ecosystem

Coastal dune ecosystems are unique habitats that harbour remarkable biodiversity and provide essential ecosystem services to coastal communities. However, these ecosystems face numerous threats that we have identified in the field (figure 8) as:

- An increasing urbanisation and infrastructure expansion;
- Sea defences and sand extraction;
- Over-visiting by tourists and leisure activities.
- Agricultural and pastoral over-exploitation: presence of goats on the dunes.

The over-exploitation of sand from coastal dunes and beaches upsets the already fragile balance of the coastline and exposes it to the aggressive action of the sea.

Figure 8 – Human activities on sand dunes.

Discussion

Coastal ecosystems in Algeria, as well as those of the Mediterranean region, have witnessed substantial changes in plant communities over time [15]. These environments face considerable degradation leading mostly to their fragmentation and destruction, affecting severely the plant communities of these ecosystems. The loss of plant diversity in coastal ecosystems is due to several factors, mainly the anthropogenic pressure such as urbanization, tourism, pollution and introduction of invasive species [3]. Climate change has also affected these ecosystems negatively. Extreme weather events like the increase in temperatures and the prolonged periods of drought exacerbates the pressure, posing further risks to coastal biodiversity [3]. Understanding the factors affecting the coastal ecosystems is of paramount importance in order to predict and manage changes in plant diversity and composition over time.

Our results indicated that the dune ecosystems in the Algiers region is experiencing a significant reduction in plant diversity, and also suggested that this loss was not a recent trend but started before 1960 and has worsened in recent years.

Conclusion

The Algiers coastline currently faces a number of significant threats, with the western side (Zeralda) more affected than the eastern side (Zemmouri). These threats include uncontrolled urbanisation, the passage of vehicles and heavy machinery over the dunes, excessive grazing, over-visiting by tourists, and sand removal. In order to stop the alarming deterioration of dune habitats and ensure their long-term survival, it is essential to consolidate the work already undertaken by ensuring the spatio-temporal monitoring of dune vegetation (station assessments). There is also an urgent need to continue the inventory of existing vegetation, monitor its demographic evolution, analyse its chorology and assess the threats to dune plant communities. In view of the worrying situation, it is essential to implement a concerted action in collaboration with the conservation structures of Algiers and the National Coastal Commissariat. Targeted conservation and restoration measures must be taken to preserve these particularly fragile habitats. It is also alarming to note that *Ammophila arenaria*, which plays a key role in fixing the dunes, is dwindling *in situ*. This species is used in dune restoration projects [10]. Therefore, in order to contribute to the conservation and restoration of the threatened dune ecosystems of the Algiers coast, it is necessary to consider reintroduction efforts.

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SESSION

GEOGRAPHY, TOURISM AND LANDSCAPE OF THE COASTAL AREA. ENHANCEMENT, SAFEGUARDING AND DYNAMICS OF THE TERRITORY

Chairperson: Donatella Privitera
Department of Educational Sciences University of Catania

GEOGRAPHY, TOURISM AND LANDSCAPE OF THE COASTAL AREA.
Enhancement, Safeguarding and Dynamics of the Territory

Climate change affects different regions differently, and although no part of the Earth is immune, scholars agree that the Mediterranean area is witnessing, and will continue to witness, more heat waves, droughts, wildfires, coastal flooding and stronger windstorms, as well as periods of heavier rainfall. Much of this occurs during the summer season, i.e. the tourist season in the Mediterranean, with serious economic and social consequences and also with disastrous results on human health, as has dramatically happened recently.

Coastal areas play a strategic role in the Mediterranean basin, one of the most important centers of biodiversity worldwide, as they fulfill natural, residential, recreational, and commercial functions of particular relevance and ancient tradition. Actually, managing and sustainably protecting marine and coastal ecosystems is more important than ever, along with their conservation and development. Therefore, analyzing and deepening our understanding of the physical, environmental, landscape, tourist, and cultural characteristics and dynamics of the reference territories are considered fundamental.

The Session *Geography, Tourism and Landscape of The Coastal Area. Enhancement, Safeguarding and Dynamics of The Territory* included, moreover, a total of 16 articles coming from different countries. Specially, the thematic area dedicated to the geography coastal strip, to the dynamics of landscapes and anthropized areas; to the history, description and classification of the landscape, to its design, planning, legislation and integrated management. Other contributions of the session were on the tourism development of coastal areas and climates change.

All papers here published provide relevant insights about important aspects of coastline geography and coastal landscapes in several districts and also countries. Since it is impossible to describe all contents of the articles in this short introduction, the focus is only on a few main insights from each paper. Determining landscape relations as a multidimensional phenomenon and changeability process the article of *Provendier* identify three levers for activating a citizen mobilisation through environmental mediation who want to take action and make their voices heard by public authorities. On the same topic*, Sopina* and *Bojanić Obad Šćitaroci* find that the landscape archetypes aid in dealing with the complex natures of the urban and natural landscape relation by acknowledging the values found in (different intensities) in all landscapes.

The coastal areas are as a place of experimentation of innovative planning strategies, the integrated and sustainable management of the urban-maritime and local environmental heritage. *Palermo et al.* oriented to the definition of the "Blue Community" model, where the study of the interrelations between planning activities of the coastal settlements and the ecosystem services are relevant.

FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Laura Bonora, Marcantonio Catelani, Matteo De Vincenzi, Giorgio Matteucci (edited by), *Tenth International Symposium "Monitoring of Mediterranean Coastal Areas: Problems and Measurement Techniques". Livorno (Italy) 11th-13th June 2024*, © 2024 Author(s), CC BY-NC-SA 4.0, published by Firenze University Press, ISBN 979-12-215-0556-6, DOI 10.36253/979-12-215-0556-6

The urban transformations and their causes driven by economic and demographic factors affecting the 19 Abruzzo Region coastal municipalities, is analyzed by means of an approach of the Planning Tool Mosaic by *Montaldi et al.*. The knowledge of the transformative forecasts of urban plans is crucial for the identification of possible critical issues, for planning targeted corrective actions, and for the achievement of the important goals of Agenda 2030.

Martelliano and *Denaro,* in the context of south-eastern Sicily, explore the concept of visibility in the setting of wetland conservation, in order to ensure the conservation of these precious ecosystems for the future generations. Thanks to the widespread use of GIS software visibility viewshed analysis, they measure how much a portion of land is visible from previously identified points, thus highlighting visual existing interactions between wetlands and the surrounding.

Herves-Pardavila and *Loureiro* analyzed to predict future physical impacts of flooding induced by rises in the mean sea-level. They are using rule-based models as the Simplified Marsh Response Model and Sea Level Affecting Marshes Model on area of San Simon Bay, in the coast of Galicia. The finding indicate that the consequences of sea-level rise are limited when compared with other processes as erosion, which need to be better understood and modelled.

Also, *Martellozzo et al.* evaluated the impact of extreme sea level rise (ESLR) to create geographically detailed datasets that depict the inland extent under future climate change conditions, focusing on the Atlantic coast of Europe and the Euro-Mediterranean basin. The study underscores the need for targeted policy measures, significant economic investment, and comprehensive social strategies to mitigate the potential impacts of ESLR on vulnerable coastal populations.

Many studies have explored the tourism potential of coastal areas, highlighting their role in protecting, revitalizing, and rebranding cultural characteristics. Specially, *Moira et al*. in delineate the cultural capital aspects and tourism potential of life at lighthouses in Greece. The finding study confirms that ‘Greek lighthouse families’ living and working conditions constitute a versatile cultural ecosystem, and contribution to the integrity and evolution of coastal cultural identities ensuring sustainability for lighthouses and coastal areas.

Baulaz and *Fofack-Garcia*, in France, examined the impact of offshore wind farm development on tourism and leisure activities, focusing on the perceptions of tourism stakeholders and impacts on local tourism practices. The authors underline how the integration of offshore wind energy tourism with marine-coastal territories presents a multifaceted opportunity for regional development.

Other focus on tourism aspects, is the manuscript of *Ivona* and *Privitera*: they critically examined the implications of climate change for tourism in coastal areas exploring Last Chance Tourism and the disappearance destinations. Specially the phenomenon of the coastal erosion on Rotondella, a coastal place in Basilicata region, Italy. The rise of last chance tourism in this area is causing a dispute between those who highlights the devastation to the environment and those who rely on tourist income to survive as hunting becomes increasingly difficult.

Massaro et al. studied the development of fishing tourism in Tuscany; in particular a case study in Viareggio provided useful information and advice about this activity. In Tuscany, fishing tourism is well represented in many harbors, and it has a great future, linking professional fishery and tourism creates opportunity, representing an alternative source of income. In addition, *Armanasco et al.* studied, in the islands of the Tuscan Archipelago, terraced agricultural areas through territorial analysis (mapping and geomorphological variables) and characterization of the typological characteristics of the stone artefacts. The finding highlights the integration of the evolution of the territory with the pre-existing textures, at the same time improving the ecosystem value of the rural territory.

Alongside the coastal sector of the city of Naples, *Di Pace et al.*, aimed to collect data on small-scale fisheries and its connections with the fishing sites nearby the Marine Protected Area Gaiola Underwater Park, also to evaluate possible positive effects on fish stocks due to the protection activities and the strong reduction of illegal fishing inside the Marine Protected Area.

Efstratiou studied to set a framework of actions necessary to transform a coastal recreation area to a designated bathing beach, suited for use with no health concerns. In this systematic, analytical, step by step Coastal Zone Management approach, it is a guide to the competent authorities to design and develop a listed bathing beach.

On this research area, *Robert and Trémélo* carried out a study on beaches, in Marseille, France, to characterize the experience of going to a beach, user practices and preferences, in relation to management methods. Also, understand the functional integration of the beaches into the city, and enable local authorities to take a critical look at their actions. Through a sample of beach users interviewed, the finding help to better understand beach attendance as a system within the city at various time scales and throughout different geographical locations. They also help providing guidelines to set up a more ambitious and complete system to monitor beach attendance and practices.

Masia et al. utilizing the European Charter for Sustainable Tourism, - management tool for protected areas that promotes the implementation of sustainable tourism for both the environment and local communities - focuses their article on the Asinara National Park (Sardinia, Italy) as a case study of the ongoing application of the charter. Through a methodology involving official documentation analysis and the Park's entrepreneurial landscape, results suggested a systemic vision of stakeholder engagement in creating a model for best practices to qualify the socio-economic network.

Concluding this short introduction, I'd like to thank all the authors for their valuable articles, and also the scientific and organizing committee for all the help during the Symposium. I wish all of you together to the scientific committee of this session a pleasure and interesting read of the articles published.

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AGRICULTURAL TERRACED SYSTEMS OF THE TUSCAN ARCHIPELAGO: TYPOLOGICAL ANALYSIS AND RECOVERY POSSIBILITIES OF DRY STONE WALLS

Paolo Armanasco, Leonardo Conti, Michele Moretta, Alberto Masoni, Stefano Camiciottoli, Enrico Palchetti

Abstract: In the islands of the Tuscan Archipelago, dry-stone walls represent an extensive cultural heritage in state of generalized abandonment. Considering the multifunctionality recognized to surviving terraced systems needs to be safeguarded through surveys aimed at providing characterization and indications for possible recovery interventions. After a preliminary quantitative G.I.S. remote analysis, qualitative characterization of the realities deemed most significant was carried out by on-site surveys. 48 sample areas have been analysed by studying parameters related to constructive, functional aspects and state of conservation. A variety of construction and management techniques has been found and it appears that there are strong differences in the state of conservation even between neighboring fields: on one side farmers and virtuous private individuals who maintain the terraces, on the other side, abandoned areas where the decay produces a fragmentation of the landscape continuity and originates sometimes non-negligible potential danger situations. Thus, technical indications are proposed for the restoration of degraded structures requiring priority interventions.

Keywords: dry stone walls, features analysis, state of conservation, land abandonment

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Paolo Armanasco, Leonardo Conti, Michele Moretta, Alberto Masoni, Stefano Camiciottoli, Enrico Palchetti, *Agricultural terraced systems of the tuscan archipelago: typological analysis and recovery possibilities of dry stone walls*, pp. 339-352, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.31

Introduction

Dry-stone works are the result of centuries of hard work and a stone culture that has developed in the various territories in relation to the peculiarities of the natural and socio-economic resources, as well as the changing historical circumstances, thus maturing formal expressions closely linked to the place [11]. Dry-stone walls typically are used to delimit properties, protect the growth and development of plants by creating favourable microclimates, interrupt the slope's steepness in order to control erosive phenomena on cultivable land, regulate water and create structures for the accumulation of soil and interstitial water [6] the latter being key factors in Mediterranean areas characterised by water scarcity in the summer months and intense rainfall with often destructive effects [10]. The concomitance of a number of factors, such as the abundance of suitable stone material without the possibility of valid alternatives, the need to build structures for soil defence and shelter in uncomfortable conditions, lead to the construction of this type of artefacts.

The vast majority of stone terraces that we observe today originated in the late 1800s and early 1900s [12], partly because older artefacts were demolished by natural agents due to abandonment or by man himself. The spread of terracing practices cannot be separated, in Italy as in the rest of the Mediterranean basin, from that of crops and the main agricultural techniques. It is evident that the development of fallow agriculture, i.e. an alternation on the same plot of land of annual crops for one or more years with a more or less long period of use as meadow-grazing, has favoured the arrangement of slopes with long-lasting structures [11]. Another decisive factor for the spread of terracing was population growth and hence human pressure to wrest more and more land from nature for the production of foodstuffs, especially in those territories, such as the Tuscan Archipelago, where the conformation of the terrain does not provide large flat areas or easy access.

The shapes and sizes of dry-stone terraces are quite variable and every terracing [1], like every site, has its own specificity in that it is an expression of the different ways in which the relationship between man and nature has manifested itself over time: "it constitutes a unicum, limited, perishable, unrepeatable, it has "its own process of development, its own history... reflecting the societies and cultures that conceived it, built it, used it or, in any case, came into contact with it", as the Italian Charter for Historic Gardens states [7].

The theme of the terraced landscape includes, in addition to the theme of historical and cultural heritage, the constituent dynamics of sustainable development in its local and territorial declination [13], interacting transversally with extremely topical issues such as hydrogeological defence [2], agriculture and food quality, the conservation of natural habitats [5] and rural tourism [14]; all interconnected elements that are adherent to the territorial reality of the Tuscan Archipelago. It is also an undeniable fact that the abandonment of terracing and slope arrangements in general speeds up the onset of hydro-geological instability phenomena and exacerbates their consequences in the short-medium term on the economic and social structure of the territories concerned.

In order to effectively direct future maintenance work, the Tuscan Archipelago National Park (PNAT) commissioned DAGRI (the Department of Agricultural, Food, Environmental and Forestry Science and Technology of the University of Florence) to carry out a project entitled *'Detailed study of the heritage of dry-stone walls in the Tuscan Archipelago'*. This project aimed to study terraced agricultural areas through territorial analysis (mapping and geomorphological variables) and characterization of the typological characteristics of the stone artefacts. In addition to these aspects, technical advice has been provided on how to protect and restore damaged terrace systems. The evidence discussed in this article is a selection from the extensive discussion in the publication that was produced at the end of the study on behalf of the PNAT.

Material and Methods

The archipelago is located off the Tuscan coast, between Livorno and the Argentario promontory. The main islands that make up the archipelago are seven and cover about 300 km^2 (Gorgona 2.23 km^2, Capraia 19.3 km^2, Elba 223.5 km^2, Pianosa 10.2 km^2, Montecristo 10.4 km^2, Giglio 21.2 km^2, Giannutri 2.6 km^2). All the islands, except Pianosa and Giannutri, have a lively and mostly steep relief, although they reach modest heights.

Given the size and complexity of the area analysed, a quantitative analysis methodology was developed for the preliminary identification of the more representative areas in terms of terracing intensity indices. This made it possible to focus the research on the most significant areas of the territory and above all on the areas of greatest public interest (e.g. public roads and highly frequented areas), subsequently characterising the individual systems identified in qualitative terms. The research protocol was developed in 3 main phases sequential to each other.

The first phase, that is the quantitative analysis of the terraced systems was conducted in a GIS (Geographic Information System) environment, using the QGIS software for the management of the information layers required for the spatial analysis.

Using this information, the boundaries of the future sampling areas were traced, which are in any case to be considered not perfectly adherent to the actual boundaries of the areas surveyed (often some areas were found to be simply inaccessible due to natural and/or anthropic barriers), but rather as an indication of areas of territory in which to find similarities in conformation, as well as a way to better manage the volume of sites surveyed (Figure 1).

Forty-eight sample areas were identified in which to carry out field surveys. More specifically: 25 on the island of Elba, 6 on Capraia, 10 on Giglio, 4 on Pianosa, 2 on Gorgona. Given the reduced extension on Giannutri, a single area was defined (1). The preliminary topographical analysis on Montecristo did not provide enough evidence to justify carrying out qualitative field surveys.

In the second phase, each site within the identified areas deemed representative was investigated during the on-site survey operations in order to obtain qualitative and typological characterization. In situ data collection was carried out through the compilation of a survey form prepared by means of a dedicated smartphone application (JotForm) or alternatively in a hard copy version.

The on-site visits in this phase (Figure 2) were essential to gather information that could not be found through the cartographic survey that characterized the first phase of analysis (e.g. construction aspects, cover vegetation state of conservation, as well as its actual extension). In total, an area of 40 km^2 was surveyed.

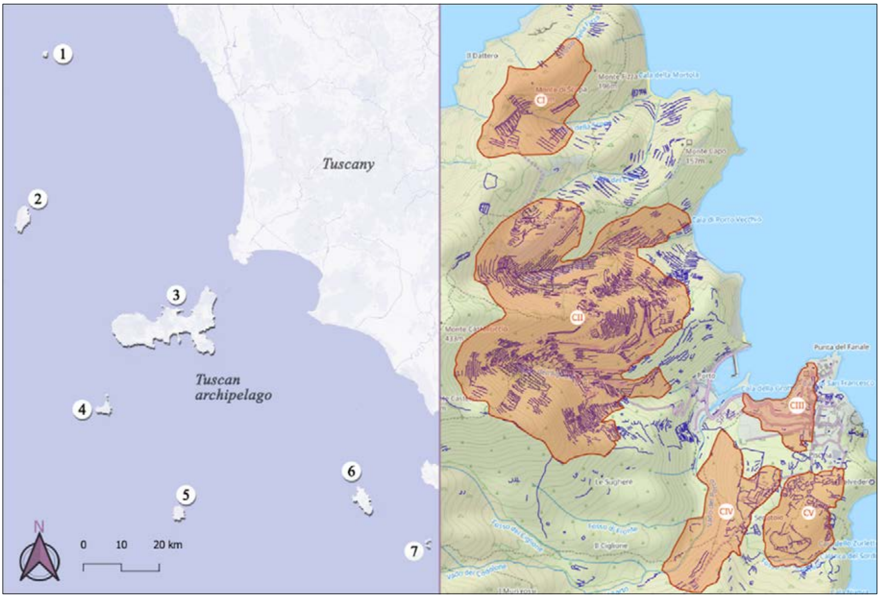

Figure 1 – Cartographic localization of the archipelago (left) and the preliminary definition of the sample areas conducted with QGIS software (right, Capraia island). The islands are: (1) Gorgona, (2) Capraia, (3) Elba, (4) Pianosa, (5) Montecristo, (6) Giglio, (7) Giannutri.

The photographic survey of the interesting and less accessible sample terraces was carried out using a drone or UAV (Unmanned Aerial Vehicle). Over the last 10-15 years, drones have become increasingly important for civil and technical applications, partly due to the development of photogrammetric techniques. The application of photogrammetric and UAV techniques makes it possible to produce georeferenced orthophotos and three-dimensional terrain models. A Mavic 2 Pro (DJI) drone with a forward speed of 5m/s was used to survey the terraced agricultural areas. Each flight mission was planned using the DJI GS Pro software in terms of height above ground, camera resolution and speed.

Using the cartography produced as part of the preliminary study (1° phase) and adding the topographic data collected in the field (2° phase), maps of each island were produced showing the location of surveyed sites. Detailed maps have also been produced within the descriptive sheet produced for each of the sample areas summarising the qualitative data collected These sheets are the result of the synthesis of the qualitative data collected.

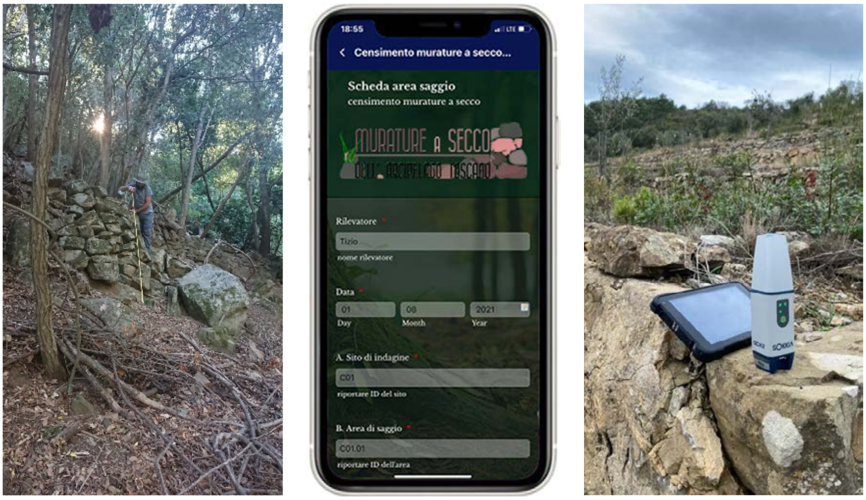

Figure 2 – Data collection operations in the second phase: manual measurement of dimensional parameters, data form on the smartphone application and drone accessories.

In the third phase, the organization on an electronic database of the data collected in the field allowed their subsequent numeric analysis and synthesis representation through graphs. The information thus synthesized provides an overall picture that briefly describes the consistency and state of conservation of the Tuscan Archipelago's dry-stone masonry heritage.

Results

The results of this study are numerous and varied. Firstly, useful maps have been produced to identify the most interesting terraced areas in the Tuscan Archipelago. A second important achievement is the production of a description sheet for each of the areas identified, which, in addition to locating the sites studied during the fieldwork on detailed maps, provides useful information on the type of wall studied, the state of conservation, the proximity of paths and whether it falls within the boundaries of the Tuscan Archipelago National Park. The numerical analysis of these data then made possible to graphically summarise most important information from the census and focus on critical points. Last but not least, all the aspects that need to be taken into account when carrying out maintenance or reconstruction work on dry-stone walls have been studied, from the technical to the regulatory aspects.

The 48 sample areas identified cover a total area of 4075 ha analysed, which represents about 15 % of the total area of the Tuscan Archipelago. A total of 394 sites were surveyed on site and analysed. 58 % of them are located in the territory of the National Park of the Tuscan Archipelago.

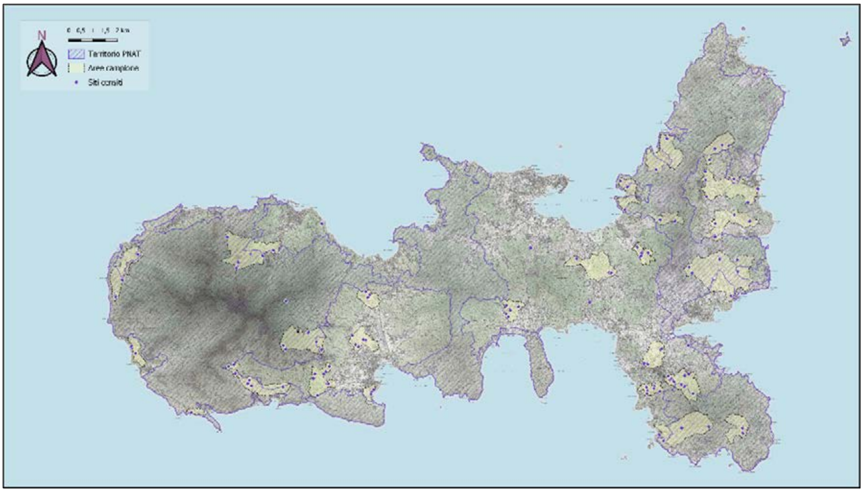

Figure 3 – Map of the Island of Elba showing the 25 areas with 30 sites surveyed.

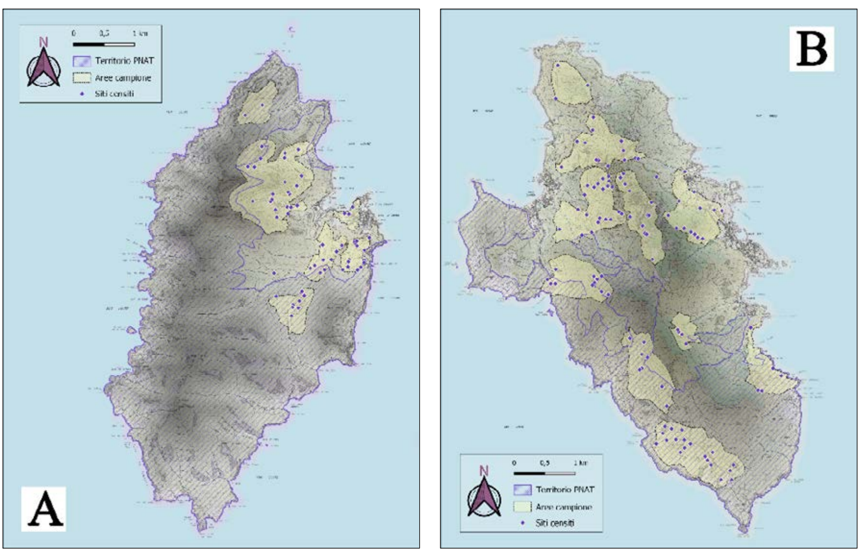

Figure 4 – Map of the Islands of Capraia (A) and Giglio (B) showing 6 sample areas with 60 sites on Capraia and 10 sample areas with110 sites on Giglio.

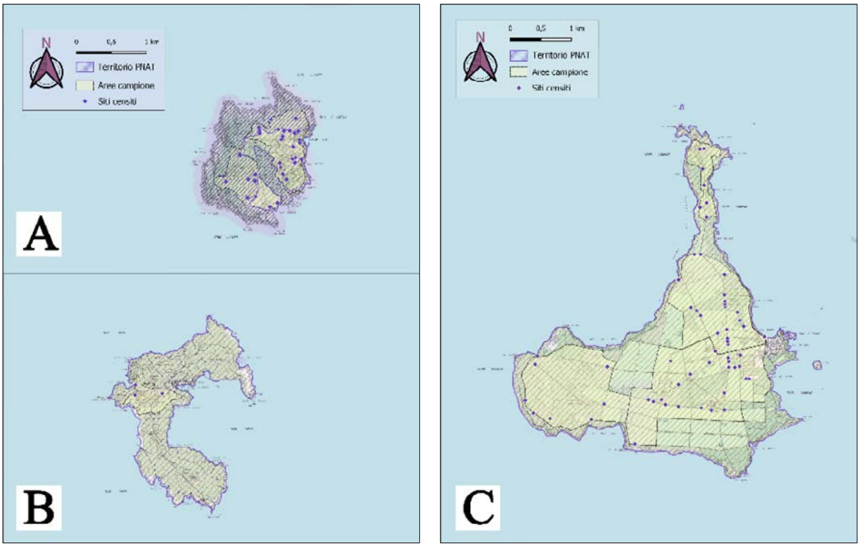

Figure 5 – Map of the Islands of Gorgona (A), Giannutri (B) and Pianosa (C). Maps shows localization of: 2 sample areas with 32 sites on Gorgona, 1 sample area with 3 sites on Giannutri, 4 sample areas with 59 sites on Pianosa.

Three basic types of dry-stone wall were identified in the present study: terracing (t), road support (rs) and boundary perimeter (bp). These typologies identify different functions for which the masonry was built. 58 % of the sites surveyed fall within the territory of the Tuscan Archipelago National Park (PNAT).

Table 1 – Number and typology of sites surveyed during the second phase of the field survey.

	Sites	Dry-stone wall typology		
Island	number	t	rs	bp
Elba	130	40 %	46 %	14 %
Giglio	110	49 %	16 %	35 %
Capraia	60	42 %	36 %	22 %
Pianosa	59	5 %	15 %	80 %
Gorgona	32	55 %	37 %	8 %
Giannutri	3	33%	0 %	67%
Total	394	153	120	119

Although three types of dry-stone walling have been identified, only the first two will be analysed here below, as they are typical of the context of terraced slopes and most uniformly characterising the agricultural landscape of the area under examination, as well as the usually considered in the sector literature. Moreover, all these structures can be considered as a whole, since even the walls used to support the road infrastructure are, in most cases, one of the steps that make up a more complex terracing system, and are therefore fully comparable with those that precede and/or follow them along the slope. No graphs are shown for two islands. In particular, Pianosa because there are almost exclusively walls with a boundary function (the island is flat), Giannutri because of the paucity of data collected (drystone walls are practically absent here).

The data presented are organised as follows: from left to right, for each island there are graphs about the shape and size of the stone elements (grey), the cover of vegetation on the terraces and walls (green), the state of conservation and the causes of any deterioration (blue).

The grey graph shows a division between (A) opus incertus and (B) opus polygonal and a division between (a) small, (b) medium and (c) large stones. The green graph shows a subdivision between (V) spontaneous vegetation, (C) crops and (N) no vegetation and a subdivision between types of spontaneous vegetation, i.e. (a) tree, (b) shrub (c) herbaceous and (m) mixed. The blue graph shows a division between (I) intact and (D) damaged masonry and a classification of the causes of degradation, namely (a) natural, (b) anthropogenic and (c) mixed.

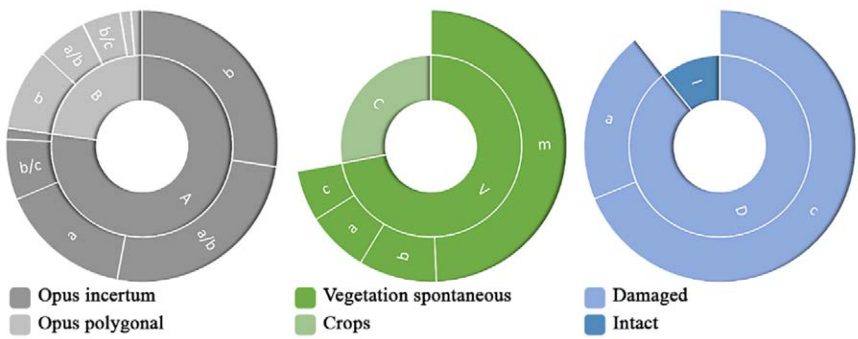

Figure 6 – Graphical summary of data for the island of Elba.

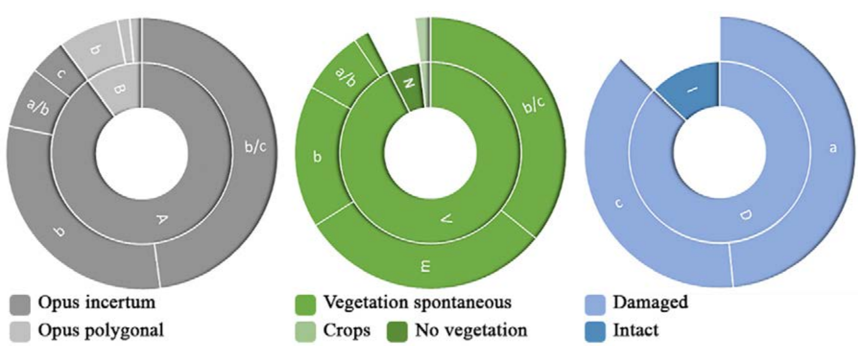

Figure 7 – Graphical summary of data for the island of Capraia.

On Elba Island (Figure 6), 77 % of the masonry is characterized by opus incertum (A), 23 % is polygonal (B) and in 37 % of cases, the stones are of medium size (b). Spontaneous vegetation (V) is present in 72 % of the surveyed sites and is mainly (49 %) of mixed type (m). 77 % of the surveyed masonry shows degradation (D), which in 59 % of cases has mixed causes (c).

On Capraia Island (Figure 7), 90 % of the masonry is characterized by opus incertum (A), 10 % is polygonal (B) and in 49 % of cases the stones are of medium-large size (b/c). Spontaneous vegetation (V) is present in 92 % of the surveyed sites and is mainly (38 %) of herbaceous/arbustive type (b/c). 87 % of the surveyed masonry shows degradation (D), which in 48 % of cases has natural causes (a).

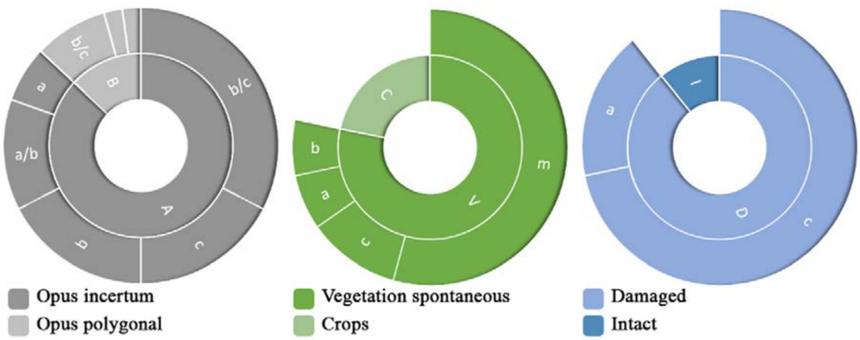

Figure 8 – Graphical summary of data for the island of Giglio.

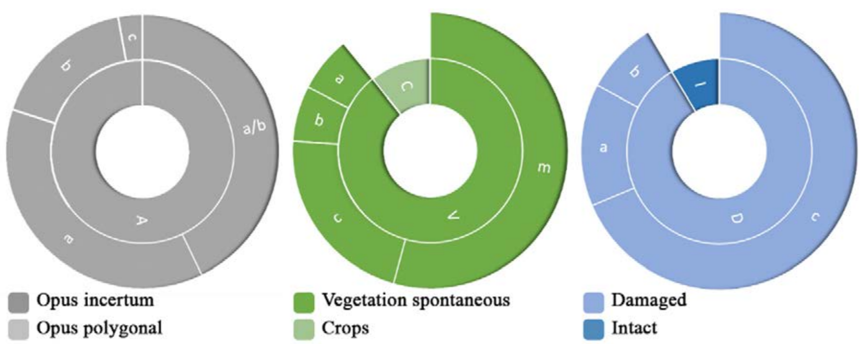

Figure 9 – Graphical summary of data for the island of Gorgona.

On Giglio Island (Figure 8), 87 % of the masonry is characterised by opus incertum (A), 13 % is polygonal (B) and in 41 % of cases the stones are of medium-large size (b/c). Spontaneous vegetation (V) is present in 78 % of the surveyed sites and is mainly (54 %) of mixed type (m). 89 % of the surveyed masonry shows degradation (D) with mainly (71 %) mixed causes (c).

On Gorgona Island (Figure 9), 100 % of the masonry is characterized by opus incertum (A) with little (a) (37 %) or little-medium (a/b) size (43 %) stones. Spontaneous vegetation (V) is present in 80 % of the surveyed sites and is mainly (60 %) of mixed type (m). 91 % of the surveyed masonry shows degradation (D), which in 68 % of cases has mixed causes (c).

Speaking about the actions that can be taken in order to maintain or restore dry stone walls, here below is reported a resume of main technical indications that have been identified within the present study.

Table 2 – Type and frequency of maintenance actions identified.

Type	Required action	Frequency
Regular inspections	1. Verify proper placement of crown stones, especially where wildlife passages occur.	3 months
	2. Verification of drainage system operation after heavy rain event.	3 months
Routine maintenance	1. Removal of vegetation that has grown in wall crevices; mature shrubs should not be uprooted to avoid damage to the structure: better an extensive pruning repeated until the vegetative potential is exhausted.	6 months
	2. Mowing of herbaceous vegetation close to the wall.	6 months
	3. Cleaning of the gullies at the foot to remove any obstructions present. Stormwater runoff must be ensured.	6 months
Occasional maintenance	1. Crowning and/or interstitial re-texturing.	when required
	2. Resolution of minor collapses if they occur.	when required
Corrective actions	Demolition and reconstruction of a section of wall with significant deterioration (spalling or collapse). Requires specialized manpower.	when required

Discussion

Regarding the first graph (grey), the size of the stone elements was assessed by counting the number of stones falling within the area represented by a 50 x 50 cm grid. Specifically, a situation was defined as small if the number of stones within the area was greater than or equal to 6, medium if it was between 6 and 3, and large if it was less than or equal to 3 stones per 0.25m² (50 x 50 cm). However, this is an average parameter derived from the need to obtain homogeneous information on a reality that is in fact very variable. Furthermore, the predominant stone geometry is opus incertum as found in peninsular Tuscany [1].

Speaking about the causes of deterioration, a condition common to varying degrees in 80 % of the walls surveyed, it is clear that they are due to natural or mixed factors. In particular, the following were considered to be natural causes: (1) the presence and/or passage of wild animals (especially ungulates, whose pressure is increasing with the progressive fields abandonment); (2) the establishment of spontaneous vegetation (which, on the one hand, can prevent soil erosion on the slopes but, on the other hand, causes the walls to crumble where the root systems penetrate between the stone elements); (3) the hydrostatic pressure exerted by the soils behind the retaining walls, exacerbated by the progressive reduction in their drainage capacity.

The causes of mixed deterioration are those resulting from a combination of factors leading to instability, such as (1) reduction in drainage capacity (silting and vegetation encroachment are the main causes), (2) collapse of the walls of the upper terraces (in the case of terraced systems), (3) erosion. It should be noted that there is always an anthropic component at the basis of these phenomena, with reference to poor management, or the absence of the same (abandonment). This is confirmed by the substantial absence of purely anthropogenic causes of degradation (grazing animals, tree cutting, use/transit of machinery) resulting from some activity carried out in the areas investigated and with particular reference to the terraced areas. Furthermore, it should be noted that while many areas appear to be maintained (mown grass and vineyards or olive groves), the dry-stone walls supporting the terraces are often collapsed or almost completely buried. With rare exceptions, therefore, intact dry-stone walls are found only on farms that derive a direct economic benefit from their costly maintenance and/or have the technical skills to carry it out.

Elba Island, the largest of the archipelago, presents a great heterogeneity of environments and situations due to the conformation of the territory, but also to processes of anthropization of the territory that are clearly more marked and invasive than on the other islands. There is a widespread condition of abandonment and degradation of the terraces that are no longer being cultivated, but also of the numerous masonries supporting the public road system or in its immediate vicinity.

On the island of Capraia the hydraulic-agrarian arrangements are concentrated within the former agricultural ex penal colony, which constitutes one of the most significant territorial emergencies. Because of their extension, typology and quality of the construction model, which have allowed them to be maintained despite decades of neglect, these terraces can be considered an exceptional historical and cultural testimony, also of great landscape importance. Other masonry and terraces were already present in the past in other parts of the island, the result of centuries of work by generations of islanders: these are the sites where the most significant degradation has been observed as they were frequently abandoned in earlier times.

Today, a large part of the land management system based on dry-stone walls has been abandoned on Giglio island, with many remains still visible. The terraces still in use are mainly vineyards and a large part of the remaining terraces are on environmental mosaics in which tree crops play an important role. Therefore, the preservation of these structures strictly depends on the continued existence of viticulture. The abandonment process is at an advanced stage of evolution towards woodland. However, the nature of the soils and the climate of the area make it possible to envisage a recovery in many of these situations.

For the conservation of terraced areas, constant ordinary maintenance works would be desirable (replacement of stone elements, cutting of weed shrub vegetation, cleaning of the main elements and accessories of the hydraulic system) rather than extraordinary maintenance interventions necessary where structural alterations occur widespread of the system itself (medium-large landslides). Restoration should be carried out in these cases using traditional dry stone construction techniques. Interventions, based on incorrect design choices and inadequate construction techniques, can trigger erosion and instability phenomena that are even more dangerous than those from which they originated.

The lack of knowledge of traditional construction practices, connected to the difficulty of handing them down by elderly farmers, suggests adopting interventions by land management bodies (e.g. Park authorities, Unions of Municipalities) to transmit a knowledge system dedicated to the actors involved. These concepts based on "know-how" may be transmitted through technical laboratories to be used for the specialized training of craftsmen and operators who will thus be able to collaborate with public institutions and farms for territory maintenance works. On the contrary, where traditional practices are not known, the applications of Nature-based Solutions are sustainable alternative solutions capable of guaranteeing high standards of functionality to terraced landscapes, albeit partially altering the distinctive characteristics of each territory.

Finally, concerning cost, those associated with drystone masonry construction or rehabilitation work are notoriously high, related, above all, to the high specialization of labor minimum 70 % incidence of the total cost) and the time required for the realization. To be specific, For the execution of maintenance operations, cost items refer to: (a) labor, (b) materials, (c) transportation of materials, (d) site organization, (e) administrative requirements.

That is why, in light of the analysis conducted as part of this study, cost optimization for dry stone wall restoration is based primarily and as far as possible on the following conditions:

1. the manpower is that of the farm or owner;
2. the material used for construction comes from the pre-existing wall or is easy to find locally;
3. the use of materials from other areas should be kept to a minimum, both to minimize transportation costs and for landscape reasons (different shapes and coloration of stone elements.

Labor is the main cost item for these works and is used for the demolition of the deteriorated parts and their reconstruction. With regard to the demolition of the deteriorated parts, the excavation on the back and foundation, and the stacking of the resulting material, it is difficult to make general estimates of manpower needs, since they are conditioned by the actual site situations: in certain cases, where space permits, part of this work can be done with small mechanical means, with great savings in execution time, but with the need to estimate the costs of using or renting such machines.

Given the prevailing geological nature of the rocks of the Tuscan Archipelago, the stone material used for drystone walls (apart from notable exceptions such as on Capraia and Pianosa) is traditionally small to medium-sized, irregular and labor-intensive to lay. Minimal processing and/or its frequent absence (opus incertus), on the other hand, saves time and labor otherwise used for a more careful selection of stone elements and their processing.

In order to return a complete survey, prices coherent with the current labor market were assumed. For the estimation, what is present in the "Price List of Works of Tuscany 2024" (published by Regional Resolution n.1384 of 27-11-2023 and freely available online) and the experience gained by some experts in the field surveyed in this regard were taken into account.

On the understanding that the information given is to be considered indicative because it does not include the specifics of individual intervention realities and because it analyzes cost items that are subject to annual variations, it is correct to assume a cost of 400-650 €/m^3 for ex novo construction and 200-300 €/m^3 for drywall restoration. The wide ranges are determined by the fact that cost items change according to the height of the work and thus the degree of complexity of the intervention. In addition, the costs we report are to be intended for interventions carried out with material collected on site and, therefore, net of any transportation expenses for the stones.

Conclusion

The survey returns a rather problematic snapshot of the current state of conservation and functionality of vast areas in the Tuscan Archipelago where the presence of dry-stone walls is marked. This is a symptom of a more general dynamic of abandonment of the territory. There are also marked differences between neighbouring areas in the same territory: on the one hand there are farms and willing private individuals who maintain the walls and terraces, and on the other, there are abandoned public and/or private areas where aggressive colonisation by spontaneous vegetation and the crumbling of the walls (by atmospheric agents and wildlife), once efficient, is causing erosion and instability. This heterogeneous situation produces a fragmentation of the continuity of the landscape and gives rise, especially near built-up areas and public roads, to situations of potential danger.

Given the size of the area in question, and given that over time many socio-economic factors have disappeared, which drove the local populations to extend the terraced areas to a great extent, it is simply unthinkable today to recover and maintain the entire heritage of dry-stone walls. However, it is possible and desirable to recover and maintain many masonry walls located near built-up areas and areas with a considerable impact on the landscape and, therefore, also subject to tourism. In these sites, a constant punctual intervention on the masonry is appropriate rather than exceptional interventions aimed at recovering large portions of walls or entirely rebuilding retaining walls, even if only damaged in some places.

Within the sphere of possible interventions to counter the current dynamic of land abandonment and degradation, the Clever Land on Elba, Capraia and Giglio Islands (CLEI) Integrated Territorial Project (PIT) deserves mention. The project, financed with funds from the PSR 2014-2020 of the Region of Tuscany, has brought together multiple actors, both public (including PNAT itself) and private, proposing the integration of the evolution of the territory with the pre-existing textures, at the same time improving the ecosystem value of the rural territory.

Acknowledgements

Special thanks go to the National Park of the Tuscan Archipelago, in the person of the park director, Dr. Maurizio Burlando, and the head of the technical office, Arch. Giovanni De Luca.

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UNRAVELLING THE OFFSHORE WIND ENERGY TOURISM

Yoann Baulaz, Rhoda Fofack-Garcia

Abstract: The study examines the impact of offshore wind farm (OWF) development on tourism and leisure activities in France, focusing on the perceptions of tourism stakeholders and impacts on local tourism practices. It aims to understand how coastal destinations can adapt to the development of OWFs, considering the emergence of new services and form of industrial tourism.

The methodology employs surveys and spatial analysis to assess the impacts on tourism and perceptions for three French OWF project. This study also explores new tourism opportunities related to OWFs, analyses their connections with other forms of tourism, and compares the potential impacts across the three projects. The findings establish a baseline for long-term monitoring of OWF impacts on tourism and recreational activities. The study concludes that OWFs can drive the tourism economy, depending on existing forms of tourism and the industry's ability to capitalize on this new diversification opportunity. It defines offshore wind energy tourism and places it in the broader context of other forms of tourism, based on initial observations from the three case studies.

Keywords: Offshore wind energy tourism, Monitoring tourism development, Mapping practices, social perceptions

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Introduction

The development of offshore wind farm (OWF) projects in France is creating major changes in marine environments, territories and landscapes. As far as tourism and recreational activities are concerned, knowledge of the impacts of offshore wind power focuses mainly on tourists' perceptions of wind energy landscapes, and how these perceptions affect their behavior, activities and, ultimately, tourist attendance [1], [2], [3], [4].

By potentially altering marine and coastal landscapes, user practices and, more generally, societies' relationship with their environment, OWF can sometimes be seen as a hindrance (restricting uses), and sometimes as a development factor for tourism (new tourist services).

In the search for a compromise between tourism development and marine renewable energies development in France, the main question is how can coastal tourist destinations evolve in the context of offshore wind farms? Such a question presupposes a diagnosis and a long-term monitoring of the state and evolution of tourist activities, practices and attendance on the territories where the OWF are built.

In addition, there are methodological challenges to consider. Tourism and recreation involve a wide range of stakeholders, and many factors influence the development of coastal tourism [5]. The installation of an OWF adds elements to the tourism and recreation mix, modify landscapes and perceptions, and encourages changes in stakeholders and tourist behavior [6]. All of this occurs within a changing socio-cultural context, evolving practices and planning policies that (re)shape coastal tourism development. In this context, how can we identify the impact of OWF on tourism, taking into account all the influencing factors? How can we measure changes in tourism practices and the evolution of tourism attendance?

Objectives

This research joins the broad field of research into perceptions of offshore wind and renewable energies in general [7].

This paper proposes an initial fieldwork effort to establish a methodology for monitoring the impacts of OWF on tourism and recreational activities. The objective is to provide a baseline assessment of the tourism-related issues associated with the deployment of OWFs at the early stages of their implementation, using a comparative approach across three OWF projects. Additionally, the aim is to identify the initial manifestations of offshore wind energy tourism and define this form of tourism.

To complement the existing literature, we aim to move away from traditional approaches that focus on tourist behavior and attendance to contribute to the field of studies on tourism practices and perceptions [6]. This approach requires the development of specific methodologies to analyze potential changes in practices and perceptions of local tourism stakeholders, whether institutionalized (tourist offices) or private tourism providers.

Methodology

The study explores how coastal tourist destinations can adapt to the development of OWFs. It employs a geographical approach, enriched with sociological insights, to define "offshore wind energy tourism," identify its presence in maritime areas, and examine its interaction with other forms of tourism.

This approach aims to characterize tourism services structurally and organically, while also analyzing perceptions from both private and public stakeholders involved in tourism development.

The methodology encompasses surveys and spatial analyses to gather both qualitative and quantitative data. This data will be analyzed and synthesized into maps to illustrate the tourism stakes in these areas and establishing a baseline for long-term studies. Additionally, the potential impacts of offshore wind energy on tourism are identified.

Study area

Three study areas have been selected, corresponding to the monitoring of three OWF projects in each French seafront:

1. The Banc de Guérande OWF, located off Le Croisic and St Nazaire in the Atlantic coast is operational since September 2022. Tourism in this territory is drive by a diverse range of habitats and landscapes, with three main touristic activities: recreational fishing, sailing, and hiking with landscape observation.
2. The Calvados OWF in Normandy, located off Courseulles-sur-Mer is scheduled to begin operating in 2025. Situated in the English Channel, near the historic Normandy landing beaches from World War II, the area is known for its heritage tourism. Visitors engage in activities such as exploring WWII relics, as well as enjoying coastal and sandy beach activities like sand-sailing.
3. The Gulf of Lion floating wind farm pilot site, located off Leucate in the Mediterranean Sea, is scheduled for beginning 2025. This area is known for its significant seaside tourism and strong wind conditions, making it a famous Mediterranean destination for kitesurfing.

These three projects were chosen because of their positioning (on each of metropolitan France's maritime façades), their technical characteristics (land-based and floating wind turbine technology; commercial and pilot wind farms) and the potential tourism issues to which they are exposed (off the coast of seaside resorts, close to special tourist attractions such as the D-Day landing beaches). The Banc de Guérande wind farm was also chosen because it was recently commissioned, allowing to identify the first potential manifestations of offshore wind energy tourism.

To delimit the study area around the wind farms, the state-of-art information was used, assuming that the impacts of OWF are primarily within the visible range of the turbines. This viewing area was set at 35 km from the turbines, consistent with the work of Sullivan et al. (2013)[8], who suggests that beyond this limit, visual impacts are moderate or even weak or insignificant.

The chosen approach is based on surveys and spatial analyses. In each of the study areas, surveys of tourism service providers were carried out between May and October 2023. The survey covered all tourist services that could be affected by the OWF (through a loss or gain of economic or non-economic benefits). This mainly concerns nautical activities, beach activities or activities in harbors or on the backshore (e.g. museums). Semi-structured interviews were conducted with service providers offering these activities, with three objectives in mind:

1. identify the content of the tourist services on each study site,
2. analyze potential changes in practices resulting from the construction or operation of the OWF,
3. qualify tourism providers' perceptions of wind farm development.

At the same time, semi-structured interviews were carried out with tourist office managers and elected officials in charge of tourism development in local authorities. The aim of these interviews was to:

1. identify local tourism issues and strategies,
2. describe the specific features of the areas studied from a tourism point of view, and identify the main tourist activities and sites,
3. identify if the development of OWF is included in the community's tourism development strategy,
4. qualify the perception of tourism managers towards the development of OWFs.

A quantitative sampling approach was not chosen. Instead, the aim was to obtain at least one representative from each tourist service and all tourist office directors within the study area. A larger sampling effort was deployed in the Banc de Guérande territory, as the OWF was already operational at the time of the field survey. Therefore, the goal was to obtain three representatives for each of the tourist services present in the territory whenever possible. In this way, 19 people were sampled in the Banc de Guérande area, 12 in the Calvados area and in the Gulf of Lion area.

Table 1 – Number and type of stakeholders met at each study site.

Study site	**Calvados**	**Banc de Guérande**	**Gulf of Lion**
Recreation service providers			
Recreational fishing	1	2	1
Sea excursions (boat, kayak)	2	3	2
Diving	1	1	1
Sea gliging sports	2	3	1
Tourism representative			
Tourist office receptionists	5	6	5
Tourist office managers	3	3	3
TOTAL	13*	17*	13*

**Some service providers propose different recreation services.*

Results

1. Characterizing local tourist destinations

In all three study sites, "blue tourism" is identified, involving travel and activities centered around beaches, coastal climates and sea-related activities [9]. This tourism significantly contributes to the economy and coastal development, characterized by specific urban and landscape features, including tourist resorts. Notable examples include La Baule (figure 1,B), and Port-Leucate (figure 1,C) developed under the "RACINE project" to redesign the Gulf of Lion coastline and create seaside resorts infrastructures for 5000 tourist beds between 1960 and 1980.

A nature tourism is also strongly developed in the backshore, focusing on nature appreciation and observation in locations away from urban areas. Several itineraries aim to showcase the natural heritage in the protected areas. This tourism is generally linked with a green tourism, that emphasizes "small scale, modest development using local labor, traditional style buildings, consumption of local product [10]. Nature, sport and blue tourism often intersect, as seen in Leucate area particularly renowned for board sports on water, known for the largest French coastal Mediterranean area dedicated to kite-surfing. In the Calvados, nautical sport such as sailing and sand yachting are also well-developed and recreational fishing in Banc de Guérande area.

Another form of tourism found on port coasts is industrial tourism, which showcases industrial sites and facilities where tourism is not the primary activity [11]. Activities include visits to companies, manufacturing facilities and both abandoned and active industrial sites. Industrial tourism often overlaps with business tourism, relative to business travel [12]. This form of tourism is prominent around the industrial port of Saint-Nazaire (Figure 1, B). The tourist office offers visitors the chance to explore the liners at the Escal'Atlantique museum, the World War II submarine base, blending industrial tourism with history and heritage tourism. In addition, some industrial companies, such as Chantiers de l'Atlantique and the Grand Port Maritime, offer tours of their facilities. In contrast, industrial tourism is less evident at the other two study sites, although Port-la-Nouvelle hosts significant port facilities (figure 1,C).

Lastly, cultural tourism, which involves discovering, understanding and appreciating the cultural, historical and artistic heritage of a destination, is still somewhat present. In the Calvados, remembrance tourism is predominant, due to the region's historical significance from World War II. This includes the D-Day landing beaches, museums like Juno Beach Centre (Courseulles-sur-mer), or the D-Day Museum (Arromanche), as well as memorials, military cemeteries and emblematic sites. There's a strong cultural identity associated with this period of history.

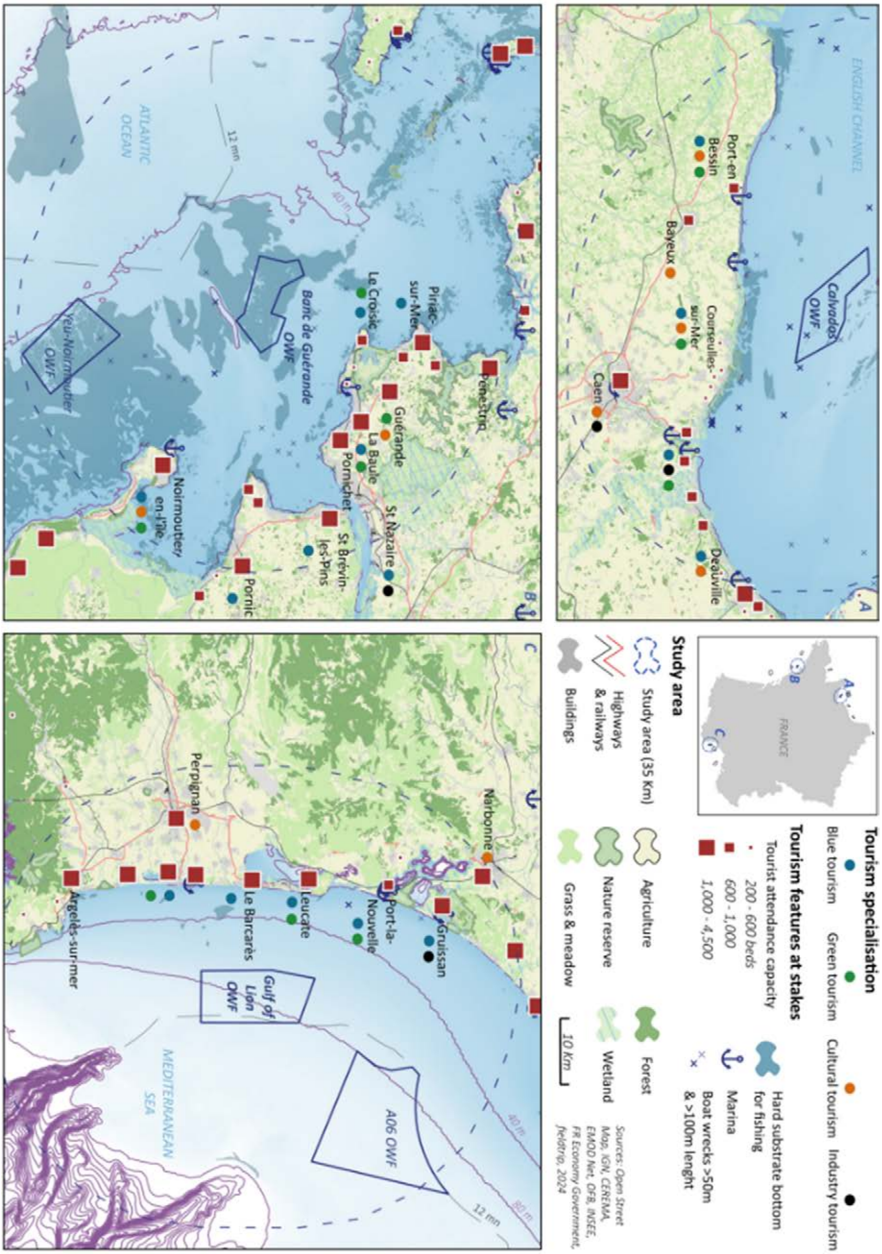

Figure 1 – Mapping of tourism issues near the three OWF case studies. The tourism features at stake were obtained from online digital data analyses, and the tourism specialisations was gathered from interviews with tourism management stakeholders.

2. Comparative analysis of the impacts of OWF on tourism and recreational activities

Fieldwork has empirically highlighted the need to distinguish between two types of potential impacts of OWF development on tourism activities. Firstly, a "material" impact, which refers to the influence of a wind farm on users' ability to carry out their activities and their spatialization. Secondly, an "immaterial" impact, relating to users' perceptions, emotions and representations of their environment, the territory and landscapes. This section, differentiate between these two types of impacts and present the new recreational practices and first manifestations of offshore wind energy tourism.

2.1 Influences of offshore wind farms on practice areas

Field surveys indicate that OWF impacts of the practice area is a crucial parameter, as the development of OWFs impose direct limitations on navigation activities. This encompasses restrictions on access to turbines, cables and inland infrastructure construction areas, as well as limitation on activities during the operation phase. While most northern European countries prefer to prohibit access to OWFs except in designated shipping lanes, France wants to minimize the impact on shipping and fishing. For the Banc de Guérande OWF, navigation is permitted within 50 meters of the turbines and 200 meters of the substation for boats less than 25 meters in length. These boats must maintain a speed limit of 12 knots and be equipped with an AIS (Automatic Identification System) transponder. Anchoring, underwater and towing activities and dragging are strictly prohibited. During construction, certain recreational activities outside the wind farm area may also be restricted, such as diving. In the Gulf of Lion OWF, diving sites along the cable route were closed for several months for example.

Activities on the beach may also be affected during the construction, with potential access prohibition of the “cable connection beach” for several months, typically outside the summer season. In return, OWF developers generally implements compensatory measures. For the Banc de Guérande OWF, the developer has funded improvements to beach services, including extending the parking area, building a ramp for disabled access, and installing sanitary facilities. In the Calvados OWF, the developer financially compensated a beach restaurant that was forced to cease operations during construction.

Other potential OWF impacts concern landscape modifications. Co-visibility issues may arise at sites where a heritage or landscape element and a wind farm are simultaneously visible, potentially affecting the attractiveness of these sites due to their associated scenery.

Assessing the landscape impact of OWFs is challenging due to its dependence on subjective parameters and its dynamic nature. Visibility of OWFs varies with distance, as wind turbines can be seen up to 40 km away or even more [8], depending on weather conditions and the turbines' technical characteristics (size, number, alignment, distance from the coast). Topography also plays crucial role, extending the horizon and making turbines visible over greater distances. Views of the ocean and OWF may be obscured by vegetation and buildings. Local weather phenomena, like coastal fog can either obscuring the turbines or enhancing their visibility through sunlight reflection. Finally, the combination of atmospheric pressure conditions and relief can create "magnifying glass effects," making the turbines appearing larger and closer. This phenomenon is particularly noticeable in the city of Guérande (Figure 1, B). Situated 40 meters above sea level and 7 km inland, Guérande offers an unobstructed view down to the sea, and this specific phenomenon gives the feeling that the turbines are positioned right on the coast.

2.2 Perception of the risks of offshore wind energy on tourist activities

This section presents a comparative analysis of the perceived impacts of OWF on tourism for each study area. The analysis is based on two axes: 1) qualitative perception of the potential impacts of OWF development on recreational activities and tourism development, 2) a semi-quantitative assessment of these perceptions. It is important to note that the semi-quantitative evaluations were conducted on a small sample of stakeholders. While valuable for inter-site comparisons and risks assessments across different items, the quantified values should not be considered in another context.

The first item surveyed addressed the impact on the landscape. We observed significant variations between sites, with predominantly negative perceptions in the Atlantic and Channel regions, and more benign to positive perceptions in the Mediterranean region. In banc de Guérande OWF, the impact on the aesthetic quality of the landscape elicited mixed views from stakeholders. Perceptions were more negative in Le Croisic and Batz-sur-Mer compared to St. Nazaire. Several stakeholders mentioned a sense of "injustice", noting that St. Nazaire benefits from the OWF project in terms of employment, tax revenues, and image, while Batz-sur-Mer and Le Croisic experience limited benefits and maximised landscape impacts. In the Calvados region, stakeholders report difficulties in visualizing the wind farm's impact on the landscape due to the fact that the wind farm construction was not finished at the time of field survey, leading to generally negative perceptions of potential impacts. Conversely, Leucate is the only area where perceptions are rated as benign to positive. Stakeholders highlight that over 200 onshore wind turbines are already visible in the retro-littoral landscape, suggesting that the OWF is unlikely to have a significant additional impact. Finally, potential landscape impacts are often weighed against the benefits of renewable energy. Many stakeholders at each site mention they are "prepared to tolerate visual nuisances if offshore wind energy helps to combat climate change." Some also mentioned a preference for wind energy over nuclear or fossil fuels concerning the landscape impacts. A sense of habituation is also evident among some stakeholders in La Baule and Le Pouliguen (figure 1,B), who mentioned that the OWF has already become a part of the landscape, six months right after the end of its construction.

Stakeholders then assessed the impact of OWFs on their activities and shared their personal opinion. Consistently negative assessments were found in the Calvados, whereas potentially positive impacts were noted in the Atlantic and Mediterranean regions. In Calvados, a small portion of local stakeholders are voicing concerns about the "image" and representations that an OWF can bring to the territory. They fear that OWFs, seen as symbols of technological innovation, could overshadow the duty of preserving historical heritage. Conversely, in the other two regions, the impacts on activities are considered benign by coastal service providers, who believe that OWFs is too far away to affect their activities. For offshore stakeholders like sailors, the impacts are seen more positively, as the OWF presents opportunities for developing new boat tour or to complement activities of fishers and pescatourism operators.

Regarding the impact of wind power on local tourism development, perceptions were slightly negative in the Atlantic and English Channel regions, but slightly positive in the Leucate region. In Banc de Guérande, at the time of this survey, tourism stakeholders do not perceive any significant changes due to the OWF. In Calvados, the arguments often reflect personal opinions, highlighting concerns about a potential conflict between offshore wind energy tourism and remembrance tourism, demonstrating how deeply this concern is rooted in the community. Institutional tourism stakeholders emphasize the economic benefits of offshore wind energy tourism, including OWF visits, marine energy exhibition centers, and educational projects. These initiatives, already present in Banc de Guérande territory, inspire Normandy's tourism sector to develop a sea-themed exhibition center that honors both D-Day events and the OWF development. This example shows that these tourism forms are not seen as conflicting by all stakeholders. In this regard, the wind farm developer even proposed naming each turbine after a D-Day landing boat. One final element that highlights the positive attitude of tourism stakeholders towards the OWF development is that in Leucate they lament the wind farm's location over 12 km from the coast. At this distance, navigation is prohibited for most recreational boaters, preventing the offering of boat trips, or other potential services.

In line with perceptions of the impact on tourism development, the effects on tourist attendance are considered benign to positive. In most cases, stakeholders mention that coastal areas are experiencing strong attractivity since COVID-19, and they believe that the OWF presence is not a factor that influence the choice of coastal destinations for tourists. Some even mentioned that OWF could attract new tourists, curious or enthusiastic about industrial tourism.

The final question concerned the impact of OWF development on territorial media coverage and promotion of the territory. Here, the results were uniformly positive, with some stakeholders feeling that their territory is being talked about much more in national news and medias because of the OWF project. This is particularly the case in Normandy. Also, the "wind's significance" in Leucate's identity greatly influences tourism stakeholders' perceptions. Known for kitesurfing and windsurfing events like "Mondial du Vent" and "Defi Wind", the region's strong association with wind and water sports suggests that offshore wind energy is well-suited, offering collaboration opportunities between wind energy developers and local sports communities.

The development of OWFs has elicited varied perceptions from tourism stakeholders across the different studied regions. In the Banc de Guérande area, the wind farm is viewed as an opportunity, with stakeholders highlighting potential economic benefits and the enhancement of existing industrial tourism. In Normandy, there are plans to integrate offshore wind energy into tourism strategy, but significant concerns remain about potential conflicts between wind farm tourism and World War II heritage tourism. In Leucate, the strong association with wind sports and existing investment in onshore wind energy has led to a more neutral stance, with potential for collaboration between wind energy developers and local sports communities. Overall, while perceptions vary, there is a general recognition of the potential benefits of offshore wind energy tourism.

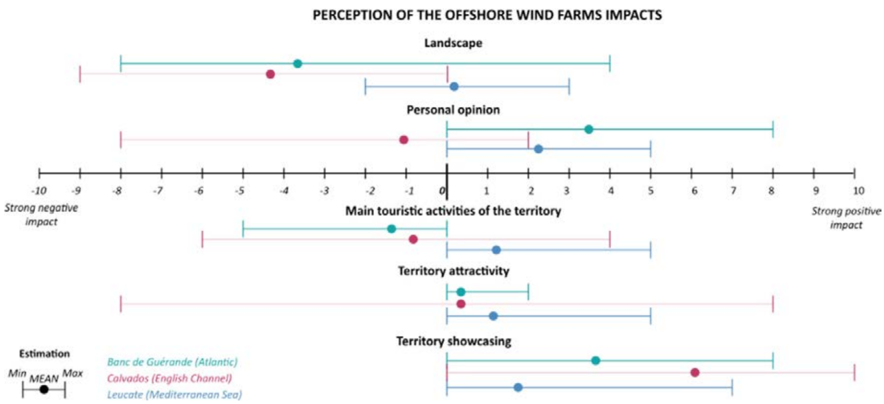

Figure 2 – The summarized evaluations of the perceptions of the impacts of OWF development on various topics related to recreational activities and tourism development strategies on the three case studies. These evaluations were averaged from the perceptions of all stakeholders interviewed. The scale used to estimate perceptions ranged from -10 (strong negative impact) to 0 (no impact) to +10 (strong positive impact).

2.3 New recreational practices linked to offshore wind energy tourism

The Banc de Guérande serves as an excellent example of how an OWF can present opportunities to further expand the already well-developed industrial tourism in the region. Local tourism stakeholders have seized the opportunity to develop a specific "offshore wind energy tourism," that can be defined as a specific type of industrial tourism attracting people interested in the technical, engineering and ecological aspects of marine renewable energies. This form of tourism appeals to various groups, including young people, families, intergenerational groups, or companies. This form of tourism reflects the evolving preferences of visitors to seaside resorts and coastal destinations. A tourism office director explains that nowadays, tourists seek more than just relaxation, beach time, or sports activities; they are increasingly drawn to experiences that offer discovery and learning. In the Banc de Guérande area, offshore wind energy tourism takes two main forms: boat tours to visit the wind farm and a museum dedicated to offshore wind energy - the EOL Center.

Since construction began in 2022, several tourism operators have incorporated the wind farm into their offerings. By the summer of 2023, four operators were offering guided boat trips to visit the OWF. The two main companies, offer cruises for large groups (25 to 130 people), and two smaller providers offer discovery tours for less than 20 people, usually combined with other activities such as introduction to fishing and visits to the coast or marshes. On average, a visit costs 70 euros per person, this activity is very popular, with all boat tours selling out fairly quickly from the start of the season and quite beneficial for operators. For example, one of the two main operators ran six cruises during the summer of 2023, allowing 1057 people to visit the wind farm, represented 28 620 € sales. In terms of content, a commentator trained by the wind farm developer and familiar with the history and operation of the OWF presents the project, its history and technical features.

Visits of turbine construction sites and manutention bases are also proposed, including tours of port facilities where the machines are stored before being deployed at sea, as well as factories where turbine components are manufactured. Most offshore wind energy tourism services occur within the wind farm viewing area, though factory visits may require travel to more distant locations (e.g. the Siemens Gamesa factory in Le Havre is located 50-100 km from the Calvados OWF).

In addition to boat and factories trips, exhibition centers dedicated to offshore wind energy are being developed. The EOL center, inaugurated in 2021 in ST Nazaire port, educates and raises public awareness of offshore wind energy. The museum welcomed 25 625 visitors in 2022. It comprises four rooms and a rooftop observatory, offering interactive exhibits and information on the history and operation of the Banc de Guérande OWF. A second exhibition center is planned in Le Croisic, focusing on marine energies and their relationship with biodiversity. Similar projects are also being considered in the Calvados region.

Finally, a significant aspect of offshore wind energy tourism is the dissemination of information regarding the wind farm's construction, operation, and environmental impact. This is achieved through permanent exhibits on information panels located along the coast facing the wind farm and at various viewpoints. Additionally, temporary information panels are set up in tourist offices and public buildings. Similarly, the enrichment of the discourse and content of guides on the various activities on the coast can also be considered here.

Discussion - conclusion

The integration of offshore wind energy tourism with marine-coastal territories presents a multifaceted opportunity for regional development. This form of tourism is, by nature, strongly intertwined with blue tourism, encompassing a wide range of activities both on the coast and at sea (UNWTO, 2008). This connection extends to various forms of tourism, including adventure, cultural, urban, rural, and nature tourism. The presence and the construction of OWF industrial projects can also enhance business tourism and the region's image as a proactive player in combating climate change, thereby promoting green and sustainable tourism.

The study conducted in three OWF case studies in each French seafront provides valuable insights into the potential impacts of OWFs development on local tourism and recreational activities. Initial findings indicate changes in recreational boating and fishing practices, as well as coastal activities within the visual range of the wind farms. These observations align with existing international literature, suggesting that the primary impacts of OWFs on tourism are localized around the vicinity of the farms and their visible areas [1], [3], [10], [13]. OWFs offer new visitor experiences, such as boat tours and exhibition centers, which have proven to be popular in the first French OWF region. More indirectly, OWF developers often contribute to local tourism development by funding local sporting and cultural events or museum restorations. These contributions represent the potential positive impacts of OWF on local tourism development.

The study underscores the varying perceptions among coastal, offshore, and institutional tourism stakeholders. While most tourism providers and tourist office staff anticipate a benign or even positive impact on tourist activities, they do not expect the wind farms to significantly influence tourists' choice of destination.

Several factors influence perceptions, including the size of the wind farms, their distance from the coast, and the importance of wind and renewable energies in the local territorial identities. Differences in territorial representation and tourism specializations play also a crucial role in shaping these perceptions. Regions with multiple tourism activities and a wide diversity of tourism forms, may be potentially less affected by OWF development, as it may diversifies local recreational opportunities. If industrial tourism is already well-developed, as in the Banc de Guérande area, then the development of an OWF can significantly boost the local tourism economy. Conversely, regions with specialized tourism, without relation to industrial tourism, such as Calvados, may view OWFs more negatively. These areas may require more targeted and innovative efforts to integrate wind energy tourism within their existing services.

Moreover, the tourism impacts of OWFs are rarely considered in relation to other socio-economic sectors or territorial development strategies. This oversight is significant, as fiscal contributions from wind farms often support tourism enhancement [6]. Additionally, tourism can sometimes conflict with other activities, such as professional fishing [14]. Given tourism's importance in public policy and coastal governance, the indirect effects of OWFs on tourism warrant careful consideration.

Future research should explore these dimensions further to better understand how to integrate tourism benefits with OWF development. The associated key question is whether the offshore wind energy tourism, driven in large part by the tourist curiosity, can be sustained in the long term.

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GAIOLA UNDERWATER PARK: SMALL-SCALE FISHERIES MONITORING AND MITIGATION OF ILLEGAL FISHING WITHIN THE FEAMP PROJECT

Gianmarco Di Pace, Maurizio Simeone, Luca Appolloni, Francesca Fabrizi, Azzurra Tommasi, Martina Defina

Abstract: This work aims to show the results obtained with the FEAMP Project, realized under the measure 1.40, in particular, results and data concerning the third target of the project: "Mitigation and fishing effort". The study was conducted alongside the coastal sector of the city of Naples, with special attention to the coastal area within the Marine Protected Area Gaiola Underwater Park and the SAC IT8030041- Gaiola and Nisida Seabeds. The project involved small-scale fishermen, members of the two cooperatives of the Naples fleet. Data on fishing effort and fishing areas were collected, in relation to the different types of fishing gear used. Data were gathered from August to October 2023, by monitoring the catch at landings. The data were related to the trends concerning illegal fishing within the MPA, showing the benefits on the catch for the small-scale fisheries due to the activities of protection carried out in the MPA.

Keywords: Gaiola, Marine Protected Area, Small Scale Fisheries, Conservation.

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Gianmarco Di Pace, Maurizio Simeone, Luca Appolloni, Francesca Fabrizi, Azzurra Tommasi, Martina Defina, *Gaiola Underwater Park: small-scale fisheries monitoring and mitigation of illegal fishing within the FEAMP project*, pp. 366-375, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.33

Introduction

This work was realized under the FEAMP 2014-2020 project, managed by the Marine Protected Area (MPA) Gaiola Underwater Park, in collaboration with CoNISMa and Parthenope University of Naples. In line with measure 1.40 of the Regulation (EU) n. 508/2014, the general objective of the project was the protection, conservation and in situ restoration of coastal and marine ecosystems and their associated resources. The study focused on the entire coastal sector of the Municipality of Naples, with special attention to the sites nearby the MPA Gaiola Underwater Park. The Park, established in 2002, covers a surface of almost 42 hectares and extends for about 2 kms along the coastline of Posillipo in the city of Naples.

Despite the metropolitan context, the MPA still preserves large area of naturalness along with bio-ecological, historical and archaeological aspects [1, 2, 3]. Furthermore, the MPA is part of the larger (167 ha) Special Area of Conservation (SAC) IT8030041 "Gaiola and Nisida Seabeds" under the Natura 2000 network. The project aimed to collect, for the first time in Naples, data on small-scale fisheries and its connections with the fishing sites nearby the MPA or the SAC, also to evaluate possible positive effects on fish stocks due to the protection activities and the strong reduction of illegal fishing inside the MPA.

Since 2015, the Park has been committed in monitoring activities, data collection and illegal fishing counteraction, in collaboration with maritime forces, succeeding in the considerable eradication of illegal fishing inside the protected area of about 97 % [4]. Furthermore, since 2020, the application of the sustainable model of fruition of the Park has contributed to the abolition of other anthropic disturbing factors in the area [4].

The project focused on the: data collection to better understand the ecological status of the existing biocenoses, with special attention to the local fish community; data collection of the fishing effort in the coastal sector concerned; monitoring of the illegal fishing activities, even to safeguard local fishermen committed in small-scale fisheries.

Materials and Methods

Data collection was conducted from August to October 2023. Twelve fishing units, members of the two cooperatives involved in the project, were monitored, out of a total still operating fleet of 29 units, with 9 units currently inactive (Fig. 1). The monitored units were selected proportionally according to the different fishing typologies praticated by the total operating fleet. Figure 2 demonstrates that the most commonly praticated fishing typology is with pots (FPO); considering the passive nets, there is an evident preference for Gillnet (GNS) with respect to the Combined (GTN) and Trammel (GTR).

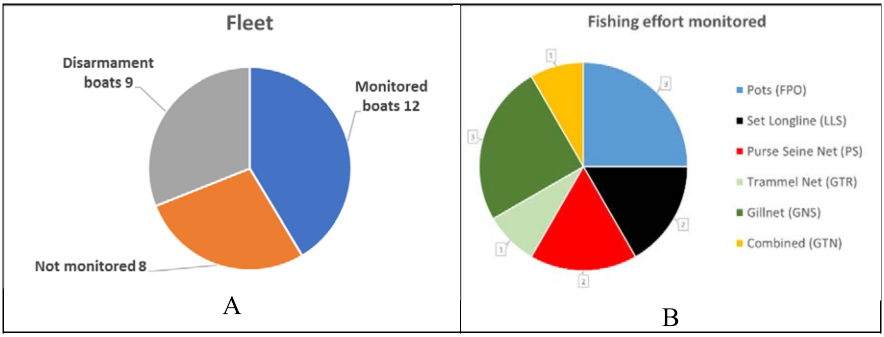

Figure 1 - A) Fishing fleet and monitored units - B) Monitored fishing typologies.

For each unit, during the landing phases, the following data were collected:

- Typology, number of fishing gear used and target species;
- Fishing areas, periods and time of installation;
- Data on the catch: size, weight, species and bycatch;
- Socio-demographic data on shipowners and crew;

Before collecting data on the catch and the fishing areas, the fishermen involved were interviewed through questionnaires in order to gather general information on their activity.

To collect data on the fishing areas, a map of the study area, corresponding to the coastal sector of the Municipality of Naples, divided into sectors, was used (Fig. 2-A).

At the same time, the monitoring of illegal fishing activities within the MPA was reinforced, through visual census of night recordings from the surveillance cameras supplied by the Park, along with night and day surveys with operators. For this activity the map of the Park divided into sectors was used (Fig. 2-B).

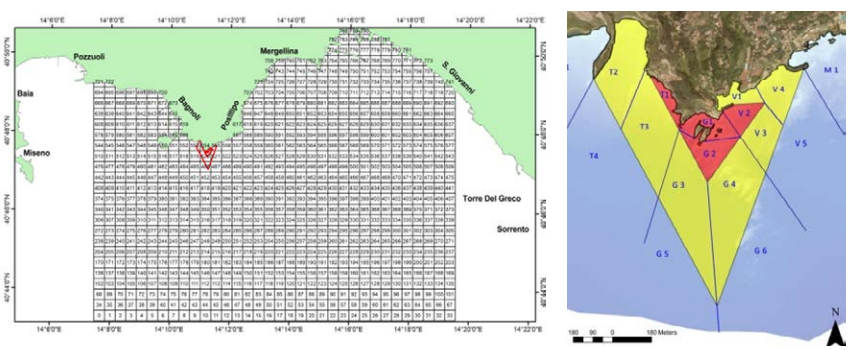

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Figure 2 - Maps used for the monitoring of coastal fishing (A) and illegal fishing (B).

The fishing units involved in the project were also equipped with a GPS tracking device, in order to collect as accurately as possible information about the fishing areas frequented (Fig. 3-A). At the end of the day, the data on the catch were collected along with the GPS tracks of the day, from which the fishing areas of catch's origin were extrapolated. Regarding the data on the catch's size (Fig. 3-B), the total lengths of the fish were measured while for molluscs and crustaceans the specific length of the coat or carapace were measured.

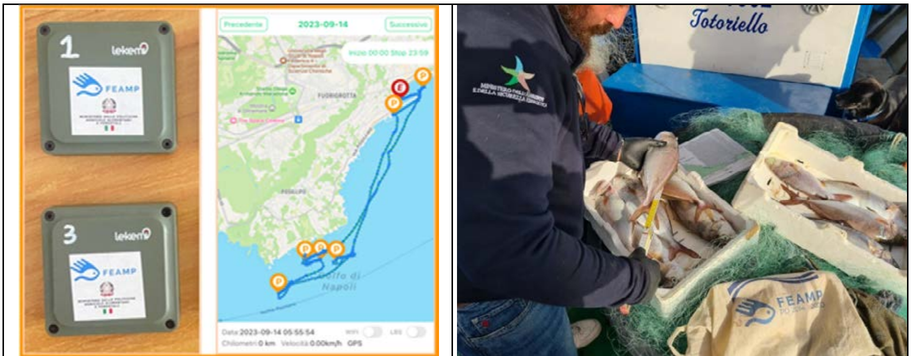

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Figure 3 - A) monitored units' GPS tracks B) Measurements at landing.

Results and Discussion

The socio-economic interviews revealed interesting data related to the fisherman's job in the city of Naples. In Fig. 4, the following data are showed: the current age of the fishermen; the age fishermen had when they started to work in the small-scale fisheries; whether the job was inherited and whether they are passing it on, in their turn.

It is evident that the average age of the fishermen is quite high and that all of them inherited the job from a family member. Furthermore, many of them started to work at a very young age, embarking with their father or grandfather, from whom they learned the job. Instead, today, only one fisherman works with his son, passing the job on.

Figure 5 shows the map of the spatial distribution of the different fishing activities. It is evident an equal distribution along the coast, identifying 5 fishing macro-areas: Nisida, Gaiola-Posillipo, Cenito-Mergellina, Castel dell'Ovo and San Giovanni.

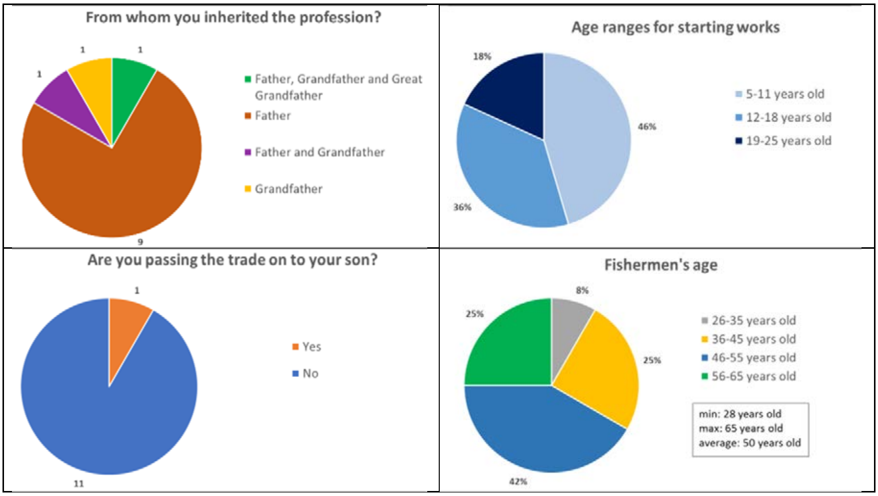

Figure 4 - Demographic data on the fishermen's activity in the City of Naples.

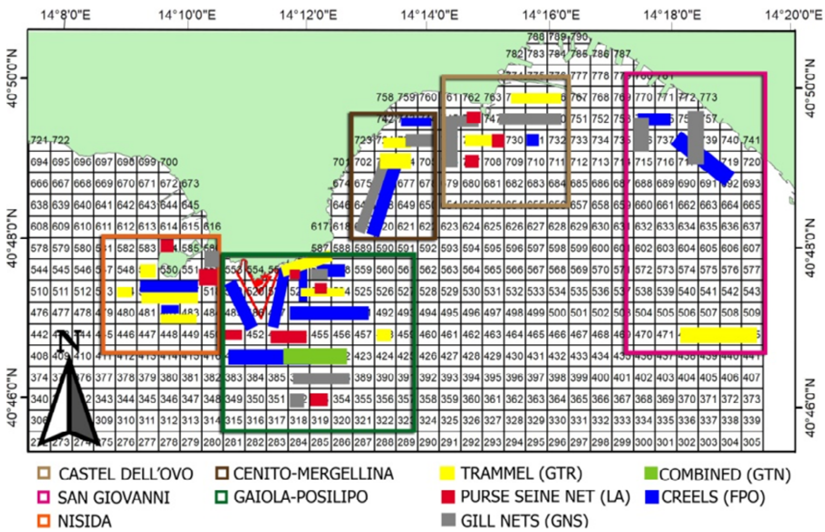

Figure 5 - Macro-areas of distribution of the fishing activities in the Gulf of Naples.

It is evident, for all the monitored fishing activities, a clear preference for the areas nearby the MPA, specifically the Gaiola-Posillipo macro-area.

The graphs in fig. 6 display data regarding the distribution and characterization of the catch in the different identified and mapped fishing sites. In particular:

- A: fishing effort for each gear in the different areas;
- B: characterization of the catch in different areas;
- C: total biomass and number of species caught in the different areas;

Comparing these data, it is clear that the Gaiola-Posillipo area is the most frequented for all the monitored fishing activities, where more than 40 % of the monitored fishing activities occur, with a predominance of fishing with pots (Fig.6-A).

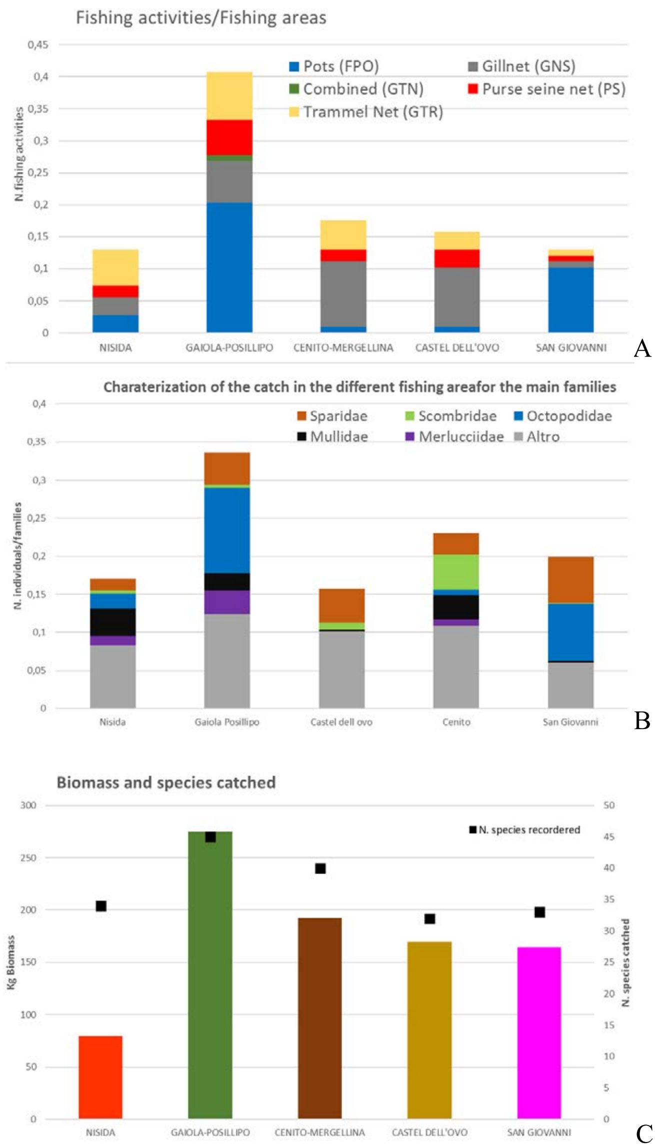

Figure 6 - For every fishing macro-area: A) Fishing effort; B) Characterization of catch for each fishing gear; C) Total Biomass and number of caught species.

It is evident that this area is perceived as the richest fishing ground by fishermen, thanks to the *spill over* effect generated by the protective measure adopted in the MPA. Observing the graphs in Figure 6-B, it is clear that the area is very rich both in terms of diversity and number of organisms. This is indicated by the highest number of different families caught, associated with the highest number of individuals per family caught. The graph in fig. 6-C confirms the data for the Gaiola-Posillipo area, showing higher values both in terms of total biomass and number of species compared to the other areas.

The following graph (Fig. 7) shows the characterization of the fishing catch in the Gaiola-Posillipo area.

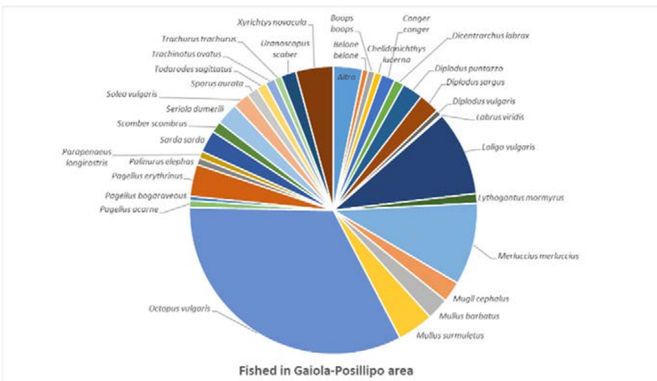

Figure 7 - Characterization of the catch in the Gaiola-Posillipo area.

In this macro-area, there is a clear predominance of octopus fishing (*Octopus vulgaris*), primarily using pots. The images in fig. 8 show the high specific fishing effort targeting octopus in the Gaiola-Posillipo area (A). Nevertheless, biomass parameters (B) for octopus in this area are significantly higher compared to other areas.

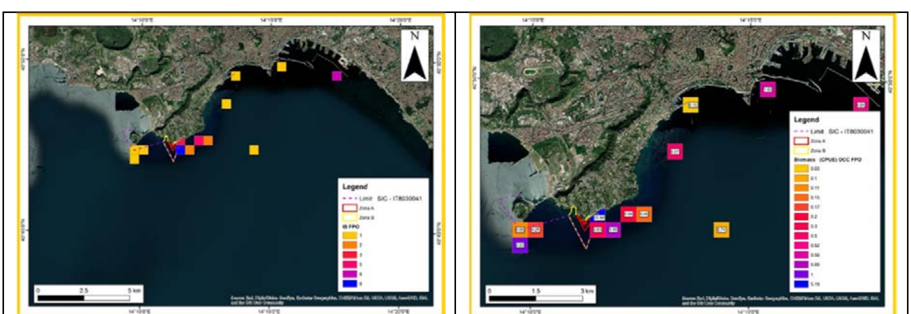

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Figure 8 - A) Octopus fishing effort with pots B) Octopus biomass captured with pots.

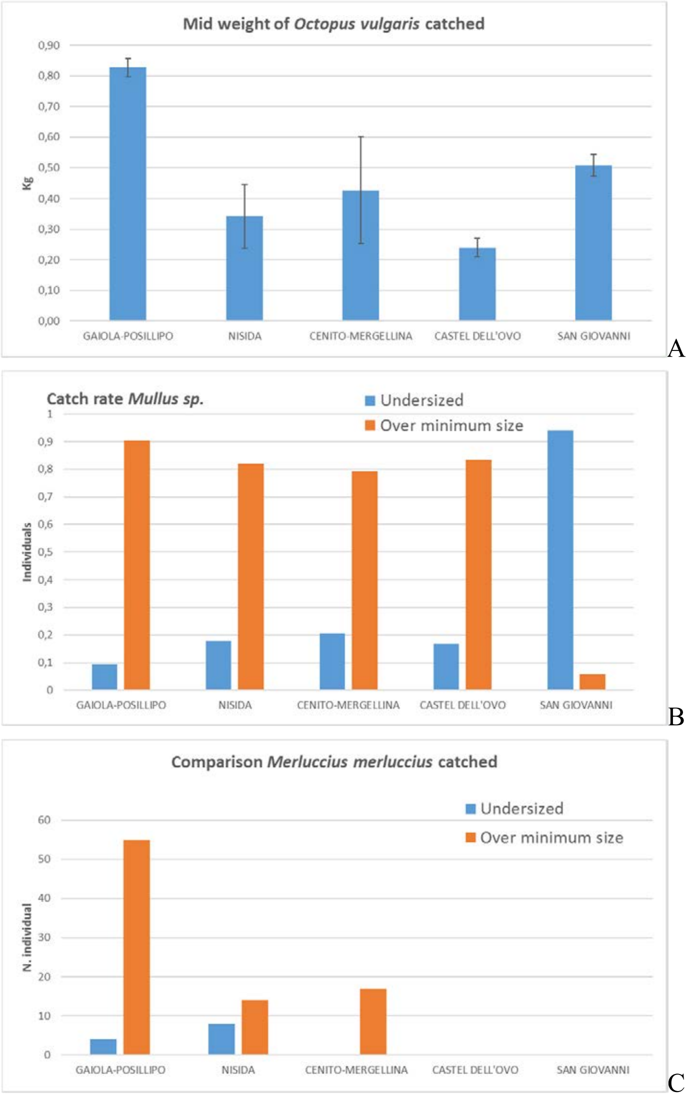
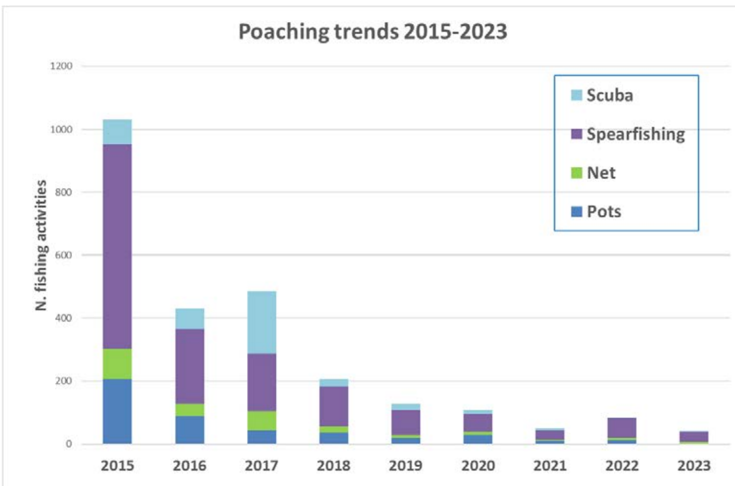


Figure 9 - For the different fishing macro-areas: A) Average weight of the *Octopus vulgaris* and number of individuals legal-sized and undersized per *Mullus* sp. B) e *Merluccius merluccius* C)

Even the average weight parameters in the Graph A in Fig. 9 confirm significantly higher values for this specie, with respect to other areas.

Similarly, this trend is observed for the other two identified target species: *Mullus* sp. (Fig. 9-B) and *Merluccius merluccius* (Fig. 9-C). Specifically, the ratio of legal-sized and undersized catch is markedly higher in the area affected by the presence of the MPA, confirming that larger and more numerous organisms of different species are caught in the MPA.

To conclude, Fig. 10 shows data on the decrease of illegal fishing activities inside the MPA Gaiola Underwater Park, from 2015 until today. There is a significant reduction of all the illegal fishing activities inside the Park (A). Some fishing typologies inside the Park have effectively disappeared, such as fishing with air breathing apparatus (B); while spearfishing activities persist above all in border sectors, albeit in greatly reduced numbers compared to the past.



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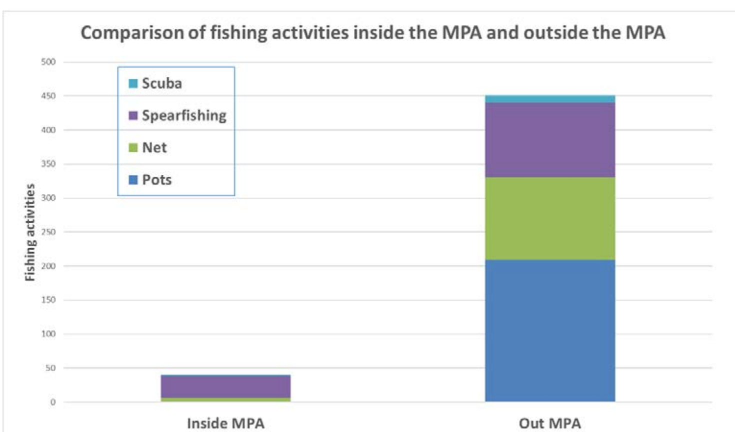

B

Figure 10 - (A) Illegal fishing activities from 2015 to 2023 inside the MPA and difference between inside and outside the perimeter of the MPA (B)

Conclusion

This work shows that the action of protection, reduction of anthropic disturbing factors and the counteraction of illegal fishing implemented by the MPA Gaiola Underwater Park are producing a positive "Reserve Effect" in terms of abundance, diversity and size of the catch in the coastal sector nearby the MPA.

This is a clear evidence of the *spill over effect* generated by the Park and perceived by the small-scale coastal fishermen in the City of Naples, who report a richer ground in the sectors nearby the Park. However, the demographic and social data on the local small-scale fisheries are concerning, showing a low, if not entirely absent, generational turnover and the transmission of the job from father to son, which has kept this traditional activity alive until today.

Undoubtedly, this project has strengthened the relationship with the local fishing community. Many fishermen, at the end of the monitoring period, admitted to feeling protected, with some even reporting the presence of illegal fishermen in the MPA to the Park Authority.

Additionally, the surveillance activity of the area through the video-camera system has not only intensified but also made the control activities of the Park, conducted by maritime authorities in collaboration with the Park's staff responsible for data collection and monitoring, more efficient.

Acknowledgments

Special thanks to the two fishing cooperatives of Molo S. Antonio in Mergellina (Unione Esercenti Pesca, Marina Nuova) who participated in the project, for their collaboration and the knowledge they provided to scientific research.

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FROM A LOVELY COAST TO A DESIGNATED BATHING BEACH: STEPS, CHALLENGES, LEGISLATIVE FRAMEWORK

Maria Adamantia Efstratiou

Abstract: Offering good quality bathing beaches to the public is a necessity faced by Local and Tourist Authorities of coastal areas. Recreation by the sea or inland waters provides multiple benefits to local communities: health, physical and social activities, the local economy through the attraction of tourists. The increase of population in the coastal zone has caused an increase in the demand of recreational spaces.

These days a multitude of coasts used (or with a potential to be used) for recreational purposes are not designated beaches. The benefits of their inclusion in the lists of designated bathing waters are substantial, because the regular microbiological monitoring safeguards public health. Additionally designated, monitored beaches become visible to international tourists through the relevant sites (i.e. in Europe through the European Environment Agency). To cover this emerging need for new monitored beaches we set a framework of actions necessary to transform a coastal recreation area to a designated bathing beach, suited for use with no health concerns. In this systematic, analytical, step by step Coastal Zone Management approach, we guide and support the competent authorities to design and develop a listed bathing beach.

Keywords: listed bathing beach, recreational bathing, standards, criteria

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Maria Adamantia Efstratiou, *From a lovely coast to a designated bathing beach: steps, challenges, legislative framework*, pp. 376-384, DOI: 10.36253/979-12-215-0556-6.34

Introduction

Designated/listed beaches became coastal areas historically used at the time when the then European Economic Community (EEC) published in 1976 the first Bathing Water Directive [4], which demanded monitoring of bathing recreational areas. At that time, the majority of beaches were not far from urban areas and holiday resorts. The increase of population in the coastal zone, the expansion of cities, the increased availability of transportation, the rapid increase in tourist visits (the most fast expanding and profitable economic sector in many countries), combined with an improvement of the standards of living, allowed people to travel farther away in pursuit of a coast to swim. The number of beaches used for recreation increased, and parallel to that more coastal areas claimed their right to be listed as designated. Each country proceeded to characterise more bathing places of marine, estuarine and inland waters. Today the situation is that in the EU alone the numbers of listed beaches is high: 14 698 marine, 7383 inland waters [2] claim the attention of bathers and attract tourists at the same time.

The Mediterranean countries are the world's leading tourism destination. This covers international and domestic tourism. More than 300 million international tourist arrivals (30 % of total world tourists) were reported for 2014 [9, 10, 11]. Tourist arrivals grew from 58 million in 1970 to 314 million in 2014, with a forecast of 500 million in 2030. (Figure 1).

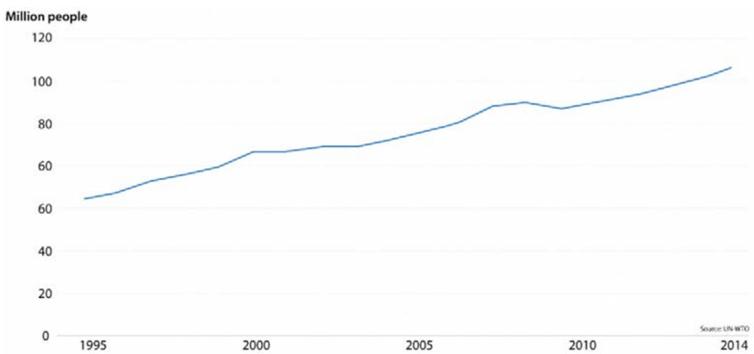
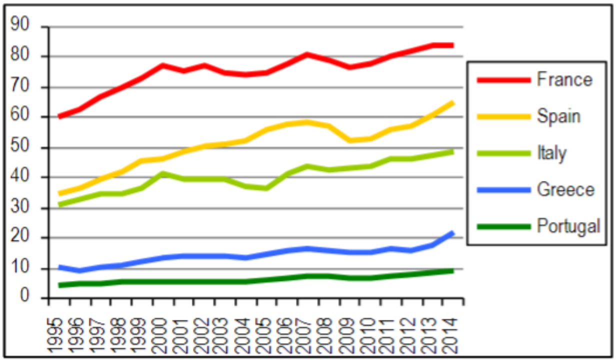


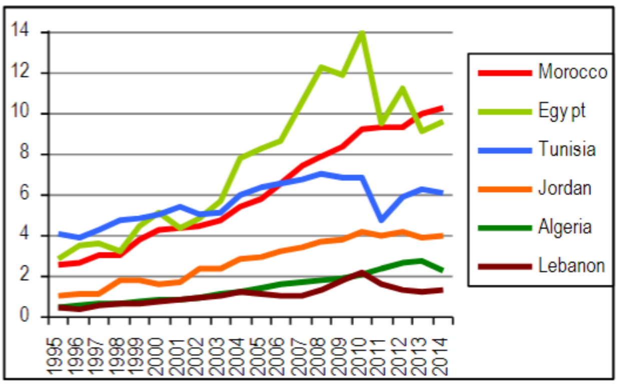
Figure 1 – International Tourist Arrivals in the Mediterranean [11].

Advanced economy countries, such as the countries of the north coast of the basin, get the majority of tourists (Fig 2), but tourist arrivals in the rest of the region are showing an upward tendency (Fig 3).



Source: World Tourism Organization (UNWTO) ©

Figure 2 – International Tourist Arrivals in the Mediterranean: selected advanced economy destinations of European countries (in million) [12].



Source: World Tourism Organization (UNWTO) ©

Figure 3 – International Tourist Arrivals in the Mediterranean: selected MENA destinations (in million) [12].

All around the Mediterranean, but mostly on the eastern and southern coasts, a multitude of beaches used for recreational purposes are not designated beaches. The potential benefits of their inclusion as listed bathing waters is substantial, because the regular microbiological monitoring safeguards public health. Additionally designated, monitored beaches become visible to international tourists through the relevant sites (i.e. European Environment Agency - Yearly publication of the State of Bathing Waters [4]). This produces an emerging need for new monitored beaches.

Our objective is to set a framework of actions necessary to transform a coastal recreation area to a designated bathing beach, suited for use with no health concerns. In this systematic, analytical, step by step Coastal Zone Management approach, we guide and support the competent authorities (Local authorities, Tourist Boards, Public Health officials, owners and operators of recreational beaches) to design and develop a bathing beach in a correct manner, adhering to current safety and sanitary requirements, with the least inconvenience and delays. We start from the issue identification and conclude with the final implementation. The legal framework set by the European Union, the World Health Organisation and the USA is discussed.

Major considerations in designing a bathing beach

To design a bathing beach with the view of achieving to get it listed/designated, one has to create a complete file and submit it to the competent authorities of their country for approval. Several points should be considered. Sanitary considerations, location, access, safety, availability of services are some of them.

Because of the critical social and economic roles, the coastal tourism industry plays, attention is required of the decision-makers and stakeholders in adopting approaches to ensure sustainable economic, social and environmental growth of this industry.

Location

All types of waters (marine and inland) can be used for bathing. Suitable coastal areas are the most frequently used for recreational purposes. In countries with extended estuarine systems, these locations can be also suitable for establishing bathing beaches. Fresh waters such as lakes and ponds, rivers and streams, have traditionally been used for recreation and may have a good potential of becoming bathing beaches and attracting beachgoers. Criteria for selecting a suitable area include proximity to large numbers of potential users: urban or holiday resort center. Favourable meteorological conditions and/or oceanography are of importance: it is preferable that a new bathing beach is established on a coast with mild winds during the bathing season. Under-the-surface water movement, in the form of currents, should not endanger bathers, so such currents should be either weak or at a distance from the coast. Beach and bottom morphology must be beachgoer friendly: the most acceptable substrate is sand or small gravel. The same goes for the bottom. The slope of the bottom should preferably be gentle. Deep waters near the coast can be uncomfortable for bathers, especially older people and children. Land use of areas surrounding the beach like ports, waste disposal areas, landfills, waste water treatment plants, animal farms, fisheries, industries emitting toxic effluents are potential sources of pollution. Boat traffic is to be completely avoided. In case the selected area is used by boats, an appropriate area should be excluded to boat traffic. Restrictions concerning environmental issues must be taken into consideration: Natura 2000 protected areas often cause difficulties in granting of permissions, other environment protection networks may cause similar problems. In most Mediterranean countries all activities are prohibited within archaeological sites, including underwater. This is a possibility that better be investigated before any attempt to proceed to organising a file for at the new beach.

Hygiene

The epidemiological evidence in the literature, from the '50s onward, suggests that there is an association between contact with polluted recreational waters and illness [6]. Children, the older and tourists who do not have immunity against locally occurring endemic disease infections, are the groups that appear to be at higher risk of disease. Microbiological examination/monitoring of bathing water is designed to protect bathers from contact with pathogenic microorganisms which could cause illness. For the shake of the safety of the beachgoers we need information on water microbiological quality data and sources of potential pollution. In the designated beaches of the European countries this monitoring is carried out routinely by the authorities, and the results are communicated to the European Commission, along with a description of the water quality management measures. They are then made available to the general public. In non European countries, particularly those investing on tourism, the water quality of designated beaches is also monitored, and measures are taken if the water quality is not satisfactory.

To complement the good hygiene level of a beach, there should be provision for toilets, hand washing facilities, showers, waste bins. Visual aspects of pollution should be removed. Animals, such as dogs, are as a rule excluded, although in some countries domestic animals are not forbidden.

Access

Easy and safe access increases the popularity of a recreational beach. Road access via a pre-existing road is desirable, as construction of a new road will add considerably to the cost of a new beach. Parking is essential. A suitable area attached to the beach is needed, large enough to accommodate the cars and wagons of beachgoers and personnel. Public transportation is not obligatory, but it is a plus, as it will allow access to a wider public. In case where access to the new beach is through private land, all necessary permissions will have to be obtained. This could take time and complicated paperwork, but many beaches are known to operate like that. Signposts are needed to signal access to the new beach. The posting of signals could be undertaken by the local authorities, but this is not always the case.

General requirements

Beachgoers' satisfaction is crucial in order to secure that the beach will be frequented. Satisfaction relies the availability of amenities that are not necessarily connected to safety, but create a pleasant - functional environment. Certain facilities are common to the majority of bathing beaches, and in demand: dressing/changing rooms, coffee shops, kiosks, picnic tables and benches. Supply of drinking, washing, showering water must be ample. Access ramps for the handicapped are a requirement. Shade provided by trees or manmade constructions is useful, especially in the warmer summer months. Beach cleaning equipment maintains not only the visual aspects of the sand, but removes dangerous small debris like broken glass particles, aluminium can openers and other hazardous articles.

Safety

Every measure should be taken to avoid health hazards and prevent accidents: first aid kits, presence of certified life guards, whistles, loudspeaker, life vests, rescue boat(s), lifesaving equipment (rescue boards, spine boards etc). Regular inspection and maintenance of beach gear (chairs, lounge chairs, tables, shade umbrellas, beach canopies and sun shades). The presence of a nurse is an added plus.

Legal Framework

Over the last 50 years implementation of existing regulations (guidelines, criteria, standards) has succeeded in achieving an overall high quality of bathing beaches. Water quality policies are not uniform, they differ from country to country, but most countries expecting a high income from tourism adhere to existing recommendations. Any new designated beach should comply with the standards used in the country it is situated.

European countries conform with European Directive 2006/7/EU [7]. This Bathing Water Directive introduced, in 2006, new principles for the monitoring and management of bathing waters, replacing the initial 1976 Directive [5]. The last had succeeded in securing the high quality of bathing waters throughout the countries of the EU, but its intervention was limited to bacteriological examination of the bathing water. The 2006 Directive introduced improved management measures, and made information for each designated beach available to the public through large signposts and the internet. Citizens are offered the opportunity to make suggestions, remarks or complaints.

In the USA the US Environment Protection Agency (USEPA) issues Criteria as recommendations/guidance to the individual States and Tribal governments [13]. They concern bacterial indicators of faecal contamination and, unlike the EU standards, they are not elaborating on the management of the beach. These criteria are used as such by the majority of the 50 States. Individual States are at liberty to use these recommended criteria as guidance and set their own bathing water quality standards. In that case they have to argue that the criteria they use are scientifically defensive and protect human health. The USEPA recreational water quality criteria are designed to protect the public from exposure to elevated levels of pathogens when bathing or occupied with water-contact activities. Recent addition to the

USEPA criteria is the introduction of the use of a microbial risk assessment approach to estimate beachgoer health risks [14].

The World Health Organisation (WHO) has issued Guidelines on Recreational Water Quality [15] which “outline health-based water quality targets and best practice for monitoring and surveillance, pollution control and communication approaches such as predictive models to let users know in real time when it is safe to go in the water”. The latest (2021) guidelines include “targets and risk management approaches based on scientific evidence and best practice from around the world summarized in several recommendations. These are meant to offer better protection of recreational water users and anticipate risks to water quality”. The WHO Guidelines are intended to provide a basis in order countries who have no other relevant standards can adhere to them for the benefit of public health.

The EU and USEPA criteria differ in several ways. In the EU the bacterial indicators of faecal pollution are enterococci and *E.coli*. In the US solely enterococci are examined for determining marine water quality, the addition of *E.coli* is required for fresh waters. They also differ in their comprehensiveness and enforceability, but also in their perceived success to date. Nonetheless overall the quality of bathing water and the safety for the bathers is at a high level. The WHO standards are more relaxed but still sufficient, when observed, to safeguard bathers’ health.

A general observation is that the countries interested in attracting international tourism adopt and apply either set of Standards (EU, USEPA or WHO), and publish on the internet their annual results of beach monitoring.

Once a beach is introduced into the list of designated beaches the Administration (competent authority) of the country has the responsibility of monitoring it and publicising the results, which leads to international recognition. For the European Union countries this is done annually by the European Environment Agency [3,4].

Discussion and Conclusions

The benefits of including a bathing beach in the list of designated beaches are numerous, all for the benefit of the local population and the revenue of the area. Designated beaches attract tourism: visitors (local tourism and tourists from abroad) support local economies in a multitude of ways, new job creation being one of many. A designated beach secures regular inspections by the authorities and the absence of pollutants that could cause health issues to swimmers. Additionally, recreation close at hand for locals is of importance. The annual monthly holiday offered by employers is a necessity, but the opportunity to relax and get some exercise at the beach during the weekends greatly enhances the good health and morale of working people. Children and pensioners can benefit from regular visits to the beach, swimming in the sea and other recreational activities. Last but not least, the creation of a new designated bathing beach means utilisation of an environmental asset.

Drawbacks could be that the creation of a new beach can be costly - or not - depending on the existing infrastructure. Running properly a beach carries a considerable annual cost, including beach managerial salaries, maintenance and cleaning staff, safety personnel etc. Extra traffic may add to atmospheric pollution, too many beachgoers may discourage bird nesting and add a burden to habitats. Generally speaking, the activities conducted within the tourism industry may contribute to many environmental problems, including climate change, natural resources depletion and losses, water and air pollution, plastic, light and sound pollution, which cause species disturbance [1,8]. It is not always easy to combine the preservation of an environmental asset to the economical benefits. Every consideration should be given to assign value to the coast whilst preserving the landscape and its ecological functions. This industry (tourism), if allowed to grow extensively and uncontrolled, may impose a negative impact on fragile natural coastline areas.

The sustainable use of the mediterranean coast by monitoring the tourist product (bathing beaches in this case), in a way that is desirable at international level, while at the same time acceptable from the preservation of the environment point of view, is a task that requires the use of multidisciplinary tools. As tourism is a major driver of the economy of coastal cities and represents a serious part of the income for the population living around coastal areas, new designated/listed bathing beaches have serious advantages for local societies and economies. Provided suitable coastal areas exist, such beaches are easy to plan. The cost of creating a new designated beach and getting it listed is weighted against the revenue expected and the benefit of access of the local population to monitored bathing waters.

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ECONOMIC VALUATION OF COASTAL BLUE CARBON STOCK'S DYNAMICS. AN STUDY IN NW SPAIN USING LAND COVER TRANSITIONS AND INVEST

David Herves-Pardavila, Maria Loureiro

Abstract: Economic valuation of ecosystem services stands as a critical element in comprehending the benefits derived from natural capital and guiding policymakers worldwide. Among these services, the regulation of CO_2 fluxes is paramount for climate adaptation and mitigation, prominently observable within Coastal Blue Carbon habitats as salt marshes. We conducted a case study of sea-level rise impacts on Galician (NW Spain) salt marshes and their carbon pools from present day to 2050. First, we compute the physical damage from flooding, using a rule-based model to identify land cover transitions. Secondly, Coastal Blue Carbon model of InVEST software is deployed to quantify impacts on carbon sequestration and apply economic valuation through the social cost of carbon. Our results indicate that the consequences of sea-level rise are limited when compared with other processes as erosion, which need to be better understood and modelled. 11 tons of CO_2 would be emitted to the atmosphere by 2050 due to sea-level rise, with damages valuated in 37 thousand €. Our approximation is useful for including the monetization of regulating services for cost-benefit analysis and coastal protection.

Keywords: Galicia, Ecosystem Services, Sea-Level Rise, Blue Carbon, Salt Marshes, Simplified Marsh Response Model, Sea Level Affecting Marshes Model, InVEST, Social Cost of Carbon, SLAMM.

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

David Herves-Pardavila, Maria Loureiro, *Economic valuation of coastal blue carbon stock's dynamics. An study in NW Spain using land cover transitions and InVEST*, pp. 385-396, DOI: 10.36253/979-12-215-0556-6.35

Introduction

The absorption of greenhouse gases emissions can alleviate the impacts of climate change. According to Wilson (2012), 44 % of all emissions are sequestered in the atmosphere, 26 % in terrestrial ecosystems, and 30 % in oceans and coastal habitats. The carbon (C) absorbed in coastal areas is referred to as Blue Carbon (Minx, 2018), with approximately 70 % found in coastal vegetated zones (Nelleman, 2009) (referred to as Coastal Blue Carbon or CBC hereafter).

CBC encompasses C stored in the biomass, sediments, and litter of tidal marshes, mangroves, and seagrass beds. The sequestration capacity of these habitats is reported to be 10 (Mcleod, 2011) to 50 (Ma, 2019) times greater on a per area basis than forest and twice as effective at storing capacities (Murray, 2011). This significant disparity can be attributed to two main factors:

1) Sediment deposition, which grows vertically without saturation, absorbs C through regular tidal flooding (Fagherazzi, 2012).
2) The anaerobic nature of their soils, where the majority of C is located (Murray, 2011), substantially reduces loss to the atmosphere through oxidation.

Coastal ecosystems face vulnerability from both land use and climate change (Hopkinson, 2012; Nahlik, 2016). Recently, a substantial portion of these areas has been converted to agricultural and industrial use (Boorman, 1999). Current estimates state that 30÷40 % of tidal marshes and sea grasses (Pachauri, 2007) and 100 % of mangroves (Duke, 2007) could be lost by the end of the century. Moreover, they are particularly sensitive to natural threats such as sea-level rise (SLR) due to their low elevations. Flooding and the consequent disruption of these zones not only imply the release of C stored over the past 100 to 1000 years (Sapkota, Y., & White, J. R., 2019; Parkinson, 1994) due to mineralization to CO_2 gas (Pendleton, 2012), but also the destruction of the potential for future sequestration. Current predictions estimate an annual release between 0,15 and 1,02 billion tons of C (Pendleton, 2012). The flooding process consists of two effects: the deposition of sediments (accretion) and SLR. If the former matches the latter, marshes may increase or maintain their extension. However, the latest SLR rates suggest that this equilibrium could be reversed (Kirwan, 2013), leading to a reduction in their surface. Nevertheless, this loss could potentially be counterbalanced, to some extent, by the migration to new suitable plains if coastal squeeze is limited.

Our area of research is the San Simon Bay in the coast of Galicia, a region situated in the northwest of Spain. The Galician coast, stretching over 1500 km, primarily features salt marshes as the core CBC habitat. Our study is, therefore, confined to this type of wetland. Our objectives are twofold: firstly, to predict future physical impacts of flooding induced by rises in the mean sea-level using rule-based models as the Simplified Marsh Response Model (SMRM) (Inácio, 2022) and Sea Level Affecting Marshes Model (SLAMM) (Warren Pinacle Consulting, 2016). Secondly, changes in land use computed by those models work as inputs for the CBC model of InVEST (Natural Capital Project, 2024), that quantifies the gas regulation by simulating CO_2 absorption or emissions. Thirdly, InVEST also valuates the damage to this ecosystem service using the Social Cost of Carbon (SCC). SCC is a measure of the loses induced to society for each new ton of CO_2 emitted into the atmosphere (Environmental Protection Agency, 2023). An economic valuation is crucial as it permits the implementation of cost-benefit analysis and generating incentives for their conservation (Lovelock, 2020).

InVEST is one of the most common tools for the integrated valuation of Ecosystem Services (ES). The CBC module has been previously implemented to assess the consequences of climate change on C reservoirs. Kadaveguru *et al.* (2022) quantified mangrove ES in Odisha (India) based on plausible future scenarios, leveraging surveys and expert knowledge from stakeholders in the region. Kotagama *et al.* (2023) assesses net sequestration and the valuation of CBC ES in Sri Lanka under several SLR scenarios. de Paula Costa *et al.* (2022) and Mortitsch *et al*. (2021) analysed C sequestration and the monetary value of mangroves and tidal salt marshes in Australia, considering different management scenarios. SLAMM was implemented by Tanner *et al.* (2023) to examine the consequences of 1m of SLR in Long Island, New York, for a 1m SLR scenario. After that, the CBC model of InVEST was implemented, including a sensitivity analysis considering three different C accumulation rates. Finding the effects of SLR are not as important as the uncertainty introduced in the model by the accumulation rates. Another application of SLAMM (Richmond, 2015) under a 1 m SLR scenario and several restoration and management regimes were developed in Port Susan Bay (US). It was found that restoration efforts are essential to maintain the ability to function as C sinks.

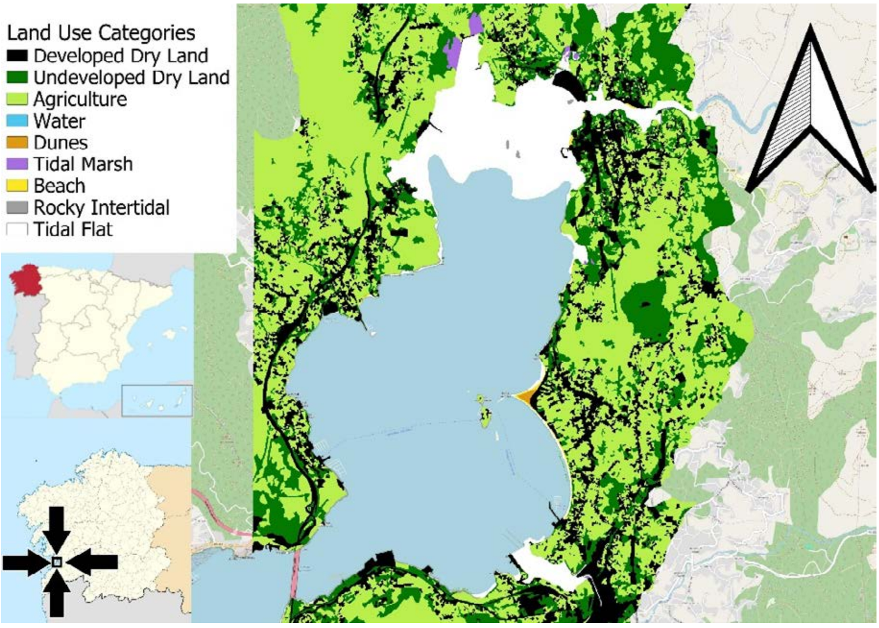

Figure 1 – Land Cover classifications of San Simon Bay. The location of this marine inlet in Galicia and the region of Galicia itself within Spain is also depicted.

Materials and Methods

SMRM, an open-source, rule-based model calculates salt marsh evolution under SLR. Developed by Inácio *et al.* (2022), it was applied in a southern Portugal case study and compared with SLAMM results. SMRM evaluates the evolution of three wetland types: tidal flat, low marsh, and high marsh. Tidal flats include land below the Mean High Water Neap (MHWN). Low marshes are between MHWN and Mean High Water (MHW), while high marshes are between MHW and Mean High Water Spring (MHWS). Terrain above MHWS is considered non-inter-tidal, classified as terrestrial land cover, and is outside SMRM's scope. Each year, SMRM accounts for sea-level rise, which lowers raster elevations and increases MHWN, MHW, and MHWS. It also factors in accretion rates increasing elevations. The interaction of these effects determines whether marsh surfaces decrease in lowland areas or increase by migrating to more suitable terrain.

SLAMM is another rule-based model requiring elevation and land cover files. If the years of these files do not match, elevations are adjusted using historical rates of global and local SLR. Elevation is the most critical parameter, as the lower elevation range of a class determines when it is inundated too frequently and thus (fractionally) converted to a different land cover. An elevation analysis tool checks if SLAMM's conceptual model fits the area of interest by comparing the assumed minimum elevation for each wetland class with the real elevations of input data. Besides flooding, we can simulate three other responses to sea-level rise: saturation of dry land (1), leading to wetland migration to adjacent uplands, accretion (2) of sediments increasing wetland elevation, and erosion (3).

Elevations were derived from a 2 m resolution digital terrain model raster provided by the Spanish National Geographical Institute (Centro Nacional de Información Geográfica - CNIG, 2024), referenced to the Spanish geographical datum. To map current salt marshes and other land uses in the area of interest, we used the 2011 cartography from the *Plan de Ordenamento do Litoral* (Dirección Xeral de Sostenibilidade e Paisaxe - Consellería de Medio Ambiente, Territorio e Infraestruturas, Xunta de Galicia, 2011), designed for urban planning and integrated assessment of the Galician coast.

Tidal data was sourced from *Puertos del Estado* (Puertos del Estado, 2023), the state-owned Spanish Port System, which manages real-time, predictive, and historical oceanographic data for several ports in Galicia. We downloaded data from the oceanographic station Vigo2 during years 1992-2012, located 13 km from the bay's centre. We computed MHWN, MHW, MHWS, mean sea-level (MSL), great diurnal tidal range (GDTR), and salt elevation (height inundated once every 30 days). SMRM uses the first three parameters, SLAMM uses GDTR and salt elevation, and both models use MSL. All measurements taken at the port of Vigo are shown in Table 1.

Table 1 – Tidal parameters. From left to right: Mean High Water Neap, Mean High Water, Mean High Water Spring, Mean Sea Level, Salt Elevation and Great Diurnal Tidal Range. All of them are expressed in meters with respect to Spain's vertical datum and obtained from Puertos del Estado (2023).

MHWN	MHW	MHWS	MSL	Salt Elev.	GDTR
0,77 ± 0,13	1,08 ± 0,04	1,33 ± 0,13	-0,1	1,9	2,45

Sea-level rise scenarios are defined by the IPCC Sixth Report (Fox-Kemper, 2021. We focus on two scenarios: SSP2-4.5 and SSP4-8.5. SSP2-4.5 deviates mildly from a 'no-additional-climate-policy' reference scenario, predicting a best-estimate warming of about 2.7ºC by the late 21st century relative to 1850-1900. SSP4-8.5 represents a high reference scenario without additional climate policy. Data is accessed via the IPCC AR6 Sea Level Projection Tool, providing projections for the nearby port of Vigo. SMRM requires inputs for SLR velocity (mm year^{-1}) and acceleration (mm year^{-2}), obtained by regressing the projections using a second-order polynomial function on a decennial time series (Table 2).

Table 2 – Sea-level Rise estimates (m) in the port of Vigo from IPCC Sixth Report (Fox-Kemper, 2021).

Scenario	2020	2030	2040	2050
SSP2-4.5	0,07	0,12	0,17	0,24
SSP5-8.5	0,07	0,12	0,19	0,26

The final set of inputs relates to marsh erosion, accretion, and saturation. Erosion is used only in SLAMM. Lacking field measurements, we used the default values of 2 m year^{-1} for marshes and 0.5 m year^{-1} for tidal flats. The accretion rate for marshes is used by both models and was computed by averaging results from a bibliographic review. We identified four studies measuring sedimentation using different techniques. These studies took place in the inter-tidal zone of the bay, close to the marsh ecosystems shown in purple in Figure 1 (Alvarez-Iglesias P. Q.-A., 2007; Pérez-Arlucea, 2024; Álvarez Iglesias, 2016; Alvarez-Iglesias P. &., 2009). We obtained values of 5.5 ± 1.1 mm year^{-1} for tidal flats, 2.3 ± 0.9 mm year^{-1} for low marshes, and 1.9 ± 0.8 mm year^{-1} for high marshes. In SMRM, the definition of low and high marshes is determined by MHWN, MHW, and MHWS within the initial marsh mapping zone. In SLAMM, the user defines the type of marshes in the land cover input raster. Comparing our initial marsh elevations with SLAMM's minimum and maximum elevations for each type of marsh, we concluded that tidal marsh was the most accurate type, assigning it an accretion rate of 2.3 ± 0.9 mm year^{-1}.

After each model run, future marsh cover provides a preliminary estimation, which tends to be an overestimation since elevation relative to tidal heights is not the only criterion for marsh existence. To refine the actual cover computation, we incorporated the following rules: retain only newly created marsh cells that intersect with marsh cells from the previous time step (1) and assume marsh migration cannot occur towards land cover types labelled as "artificial" or "rocks."

The Coastal Blue Carbon model of InVEST® is a spatially explicit tool that calculates stocks, emissions, accumulation, net sequestration, and the net present value of CBC ES. InVEST uses a simplified representation of the C cycle and relies on various inputs. The model considers four distinct pools: above-ground biomass, below-ground biomass, soil, and litter. Following Murray (2011), which indicates that 95 to 99 % of C stocks in salt marshes are concentrated in the first three meters of soil, our analysis focuses solely on this pool, disregarding the other three.

The inputs for the CBC model of InVEST consist of a time series of raster maps containing land use and land cover information. We utilize results obtained from SMRM or SLAMM, where land polygons are rasterized and categorized into nine groups: tidal flat, marsh, beach and dune, forest, scrub, cropland, water, rocks, and artificial. Notably, the marsh category is the only relevant CBC habitat for InVEST.

To simulate the C cycle, the following parameters must be supplied to InVEST: initial stocks, accumulation rates, half-life, and the proportion of C released to the atmosphere when marshes transform into tidal flats due to ocean flooding. Since our interest lies in the future accumulation or releases rather than current stocks, all initial stocks are set to zero. This decision is motivated by the idea that stand-alone environmental values (such as current C stock) do not aid the policymaking process of choosing several socioeconomic development options (Costanza, 1997). Enhancing sequestration is considered a positive flow of ES, while a decrease is seen as a negative flow or disservice. It is the potential service and disservice that is valued here (Beaumont, 2014).

Accumulation rates pose a challenge to measure due to their site-specific nature, often varying within the same marsh at different scales. In-field measurements are preferred over literature estimates. We consulted colleagues from the Biological Oceanography group of the University of Vigo (Biological Oceanography Group, 2024), who estimated an average accumulation for the whole bay of 125 g C m^{-2} $year^{-1}$. On the contrary, the half-life of C remains constant across studies and soil types, converging to a value of 7,5 years (Kacem, 2021; Kadaverugu, 2022; Tanner, 2023). Additionally, the percentage of C released by marshes when converted to tidal flats, based on studies we reviewed (Adams, 2012; Carnero-Bravo, 2018; Howe, 2009; Macreadie, 2015), is estimated at 42 % of the stock.

Economic valuation of CBC ecosystems is conducted in InVEST by defining a Net Present Value (NPV) of future stored CO_2. For each cell i in the model:

$$NPV_i = \sum_t \frac{p_t(S_{it} - S_{it-1})}{(1+d)^t} \qquad 1$$

where t ranges from zero to the number of years of the InVEST simulation. In this case, our initial mapping of the marshes dates to 2011 and lasts until 2050, totaling 39 years. P_t is a price vector indicating the cost of an emitted ton of CO_2e, and S_{it} represents C stock in cell i at year t. The discount rate d accounts for society's preferences, assigning a higher value to benefits or losses closer in time compared to those in a long-time horizon. For our analysis, we set d to 0,025, a value consistent with other studies utilizing InVEST to assess CBC ES (Kacem, 2021; Tanner, 2023) and aligning with the proposed discount rates of the United States' Environmental Protection Agency (EPA) for evaluating the SCC (Environmental Protection Agency, 2022). The price vector was also retrieved from this last source.

Results

Our initial step involves validating the models by comparing our initial mapping of the marshes with the adjustments made by the models regarding elevations and local tide levels, which make the initial area to differ from input area. According to the *Plan de Ordenamento do Litoral*, our source of land cover, the marsh extent was reported to be 14,4 hectares. However, SMRM underestimated this extent by assuming only 7 hectares before commencing the simulation. In contrast, SLAMM adjusted marsh extent to 16,2 hectares. Based on these comparisons, we decided to proceed with SLAMM simulations exclusively.

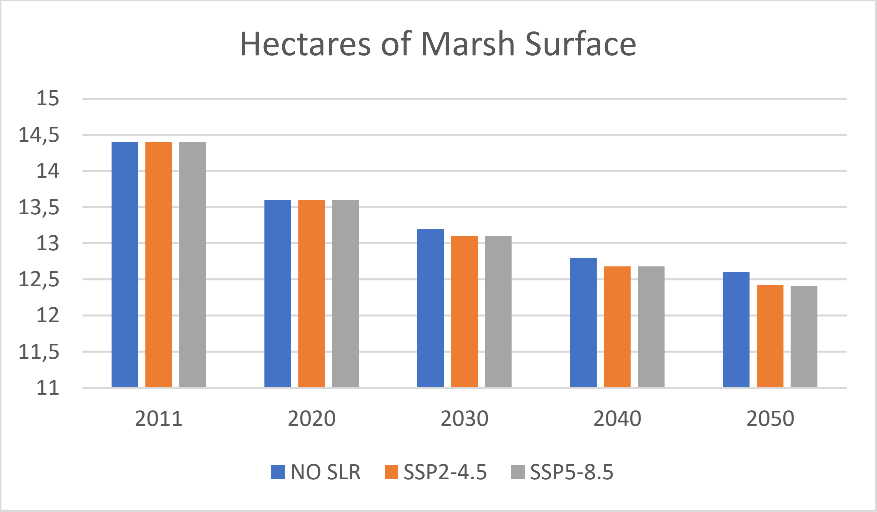

Figure 2 – SLAMM's predictions on the effects of sea-level rise on the marshes of the area of interest.

The future estimated marsh surface predicted by SLAMM is illustrated in Figure 2. Even in the baseline scenario with SLR set to zero, natural erosion is projected to decrease marsh surface. By the years 2040 and 2050, the influence become apparent, albeit limited. For instance, in the final year of the time series (2050) and in the baseline scenario, erosion has reduced the extent from 14,4 to 12,6 hectares. Under SSP2-4.5 and SSP5-8.5 scenarios, the reduction decreases further to 12,43 and 12,41 hectares, respectively.

New land use maps for the years 2020, 2030, 2040, and 2050 are rasterized and utilized as inputs for InVEST CBC. Cells where marsh has been lost and converted to tidal flats now emit a quantity of previously determined C based on its half-life. Cells with saturation of dry lands (now converted to marsh) begin absorbing carbon at a rate determined by the C accumulation rate. The results are displayed in Table 3, presenting net sequestration, emissions, and economic valuation. Overall, all three scenarios demonstrate a net sequestration of over 2300 tons by 2050. Using the SCC, this absorption equates to more than 7 million euros of benefits associated with removing this C from the earth's natural cycle, serving as a measure of the value of this ecosystem. The impact of climate change is limited to 2,4 and 2,5 emitted tons for SSP2-4.5 and SSP5-8.5, respectively, translating to 37 thousand euros in costs derived from the increase of CO_2 in the atmosphere.

Table 3 – Results of InVEST CBC model. Net Sequestration and emissions of CO_2e and Net Present Value computed using equation 1.

Scenario	Net Sequestration (10^6 kg CO_2e)	C emissions (10^6 kg CO_2e)	NPV (10^6 €)
Baseline	2378	31,3	7,157
SSP2-4.5	2368	33,7	7,119
SSP5-8.5	2367	33,8	7,118

Discussion

We compared two models for computing the impact of sea-level rise on marshes. Both models simulate the balance between flooding and natural vertical growth of marshes due to accretion (deposition of sediments). Additionally, both models utilize elevations as their main input. A key difference is that SMRM only needs to know which cells in the elevation raster are initially considered marsh ecosystems, whereas SLAMM requires a full land cover map and additional biophysical parameters. SLAMM's elevation analysis allows the user to verify if the range of elevations of the marshes aligns well with the conceptual framework of the model. In contrast, for SMRM, this verification must be done by the user themselves. We found that SLAMM only overestimates the initial cover of marshes by 12,5 %. However, SMRM underestimates it by 48,6 %. This contradicts what SMRM's developers found in a case study in Portugal (Inácio, 2022), where the area after initial adjustments remained almost the same in both models. SLAMM has been widely used for this topic, unlike SMRM, which is employed for the first time in this paper after its publication.

We have published the results for SLAMM simulations, revealing a limited effect of SLR when compared to erosion, which is present in the baseline scenario. Given that erosion is the parameter affecting the marshes the most, future improvements of our study should be guided towards collaboration with ecologists for in-field measurements of horizontal erosion. This information is valuable for local public authorities and policy frameworks such as Reducing Emissions form Deforestation and Forest Degradation (REED+) project for forest carbon offset (Herr, 2012). Blue Carbon offset programs have been worldwide applicated as well. For example, the Methodology for Tidal Wetlands and Seagrass Restoration v1.0, (Emmer, 2015) approved by Verra (Verra, 2009) (former Verified Carbon Standard (VCS)). We aim to share this and further results to the competent authorities of Galicia in the form of GIS visor, leading to the implementation of mitigation policies in our region. Besides, we hope our work encourages other researchers in the field of CBC ES to use the not-so-known SMRM in other countries and to apply InVEST on larger scales.

Moreover, forthcoming research efforts are intended to implement modern portfolio theory applied to coastal protection under sea-level rise scenarios. This approach allows us to account for uncertainty in the supply of ES (Runting, 2018).

Conclusions

Our study merges in-field local measurements with open data. This combination is necessary as marsh ecosystems and their biophysical parameters are subject to great variability and in-situ observations are a must. Sea-level rise projections, land use and elevation, which can be found in the form of open data referring to regions/countries, work well when applied to regional scales. The Sea Level Affecting Marshes Model was preferred to Simplified Marsh Response Model, revealing limited variability with respect to a baseline (no SLR) scenario until 2050. As well as a minimal difference between the climate change scenarios considered. For SSP2-4.5 and SSP5-8.5 scenarios, InVEST Coastal Blue Carbon model computed a storage of 11 tons less CO_2e than the baseline scenario due to SLR in the marshes of San Simon Bay. According to the most recent Social Cost of Carbon estimates. By 2050, CO_2 emissions would be equivalent 37 thousand € on economic damages to society.

Acknowledgements

The authors want to thank Emilio Manuel Fernández Suárez and Gonzalo Méndez Martínez from University of Vigo for their expertise and valuable support concerning the use of biophysical parameters regulating carbon capture and accretion rates in the inter-tidal ecosystems of San Simon's Bay.

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COASTAL LANDSCAPE AND "DISAPPEARING" TERRITORIES

Antonietta Ivona, Donatella Privitera

Abstract: The relationship between climate and tourism is very close, and this connection is even more evident for tourism in coastal areas. The various impacts of climate change have long been obvious in many destinations. In addition, like all sectors, also tourism contributes to the production and emission of greenhouse gases, with devastating consequences for certain areas. Through a case study, this contribution aims to reflect on territories that are disappearing due to climate change combined with excessive tourism. A new form of tourism, known as last chance tourism, has emerged as a result. In recent decades, warming in the Mediterranean has been much faster than in the rest of the world, causing serious territorial and economic consequences. Entire areas traditionally dedicated to tourism today have to deal with a drastic decrease in the number of tourists or, in some cases, an excessive increase in them to visit places with an uncertain future.

Keywords: Last chance tourism, case study, global warming, coastal erosion.

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

1. Introduction

The climate has always been a fundamental factor for tourism. The close relationship between climate and tourism is particularly evident in coastal tourism, mountain tourism, and nature tourism. Tourism is considered a highly climate-dependent activity, much like other essential economic sectors such as agriculture and transportation, to name a few. Additionally, tourism contributes to the production and emission of greenhouse gases through its various activities and requirements. Environmental conditions are a crucial resource for tourism. Changes and transformations resulting from environmental change generate a range of effects on tourist destinations. Direct effects are noticeable in the increase or decrease in tourist flows, depending on favourable climatic conditions. These changes can impact the availability of water, loss of biodiversity, modification of landscapes, and alterations in agricultural production, which, in turn, affect aspects like food and wine tourism.

Indirect impacts of climate on tourism include the exacerbation of erosion phenomena, leading to the disappearance of coastal areas and critical infrastructures related to tourist activities. There is also the threat of desertification, decreased water resources (resulting in a higher risk of fires), growing competition for alternative energy resources (resulting in increased costs for tourist services), and demographic surges of organisms like algae and jellyfish, which are difficult to reconcile with tourism. Moreover, the rising incidence of extreme events has an impact on tourist flows in the most affected areas. Out of growing concerns about issues such as global warming, loss of biodiversity, and the melting of glaciers, which threaten some of the planet's natural wonders, a form of tourism known as "Last Chance Tourism" (LCT) has gained popularity. This phenomenon involves travellers who visit threatened or vulnerable destinations, eager to experience unique and precious places before they are irreparably damaged or "disappear" due to climate change, environmental degradation, or other factors, such as disasters [15].

This study aims to critically examine the implications of climate change for tourism in coastal areas. In the context of this discussion, the study's purpose is to explore LCT in detail in the literature in the global warming and climate changes, discussing it with the help of appropriate case study related to mediterranean territories. To achieve this, we conducted thorough literature searches and utilized online search tools with keywords such as "threatened places", "disappearance destinations" and "coastal erosion".

It has been in-depth a case study in the cost of the Mediterranean area. Specially the phenomenon of the coastal erosion on *Rotondella*, a coastal place in *Basilicata* region, Italy. The rise of last chance tourism in this area is causing a dispute between those who highlight the devastation to the environment and those who rely on tourist income to survive as hunting becomes increasingly difficult. The paper wraps up by highlighting the main findings from the investigation and proposes new directions for future research.

2. Global warming and climate changes

There is no longer any doubt about the influence of human actions on the warming of the atmosphere, ocean and earth. Widespread and rapid changes have occurred in the atmosphere, ocean, cryosphere, and biosphere. The scale of recent changes in the entire climate system has been unprecedented since the remote past. It is very likely that greenhouse gas emissions were the primary driver of tropospheric warming, and it is extremely likely that human-caused stratospheric ozone depletion was the primary driver of stratospheric cooling between 1979 and the mid-1990s. It is virtually certain that the upper part of the global ocean (0÷700 m) has warmed since the 1970s.

Ocean warming accounted for 91 % of climate system warming, while land warming, ice loss, and atmospheric warming accounted for about 5 %, 3 %, and 1 %, respectively. The global average sea level rose by 0.20 m between 1901 and 2018. The average rate of sea level rise was 1.3 mm per year between 1901 and 1971, increasing at 1.9 mm per year between 1971 and 2006, and further increasing to 3.7 mm per year between 2006 and 2018. Human influenza has most likely been the main driver of these increases since at least 1971. Human influence is most likely the main driver of the global retreat of glaciers since the 1990s and the decline in Arctic Sea ice area between 1979-1988 and 2010-2019. Human influence also most likely contributed to the decline in Northern Hemisphere Spring snow cover and the surface melting of the Greenland ice sheet [11].

As warming increases, adaptation options will become more limited and less effective. At higher levels of warming, losses and damage will increase and additional human and natural systems will likely fail to adapt to the changing conditions. It will therefore be necessary to find transversal and integrated solutions that can help living systems in their ability to adapt. The risk of “maladaptation” can be avoided or at least reduced through long-term planning and the implementation of flexible, multisectoral and inclusive adaptation actions. (Figure 1). Further global warming in the coming years will be driven by future emissions and will affect all major components of the climate system, as each region will experience multiple, concurrent changes. Many climate-related risks are considered higher than previous assessments, and the expected long-term impacts are significantly higher than those currently observed. Multiple climate and non-climate risks will interact, resulting in overall and cascading risks across all sectors and regions.

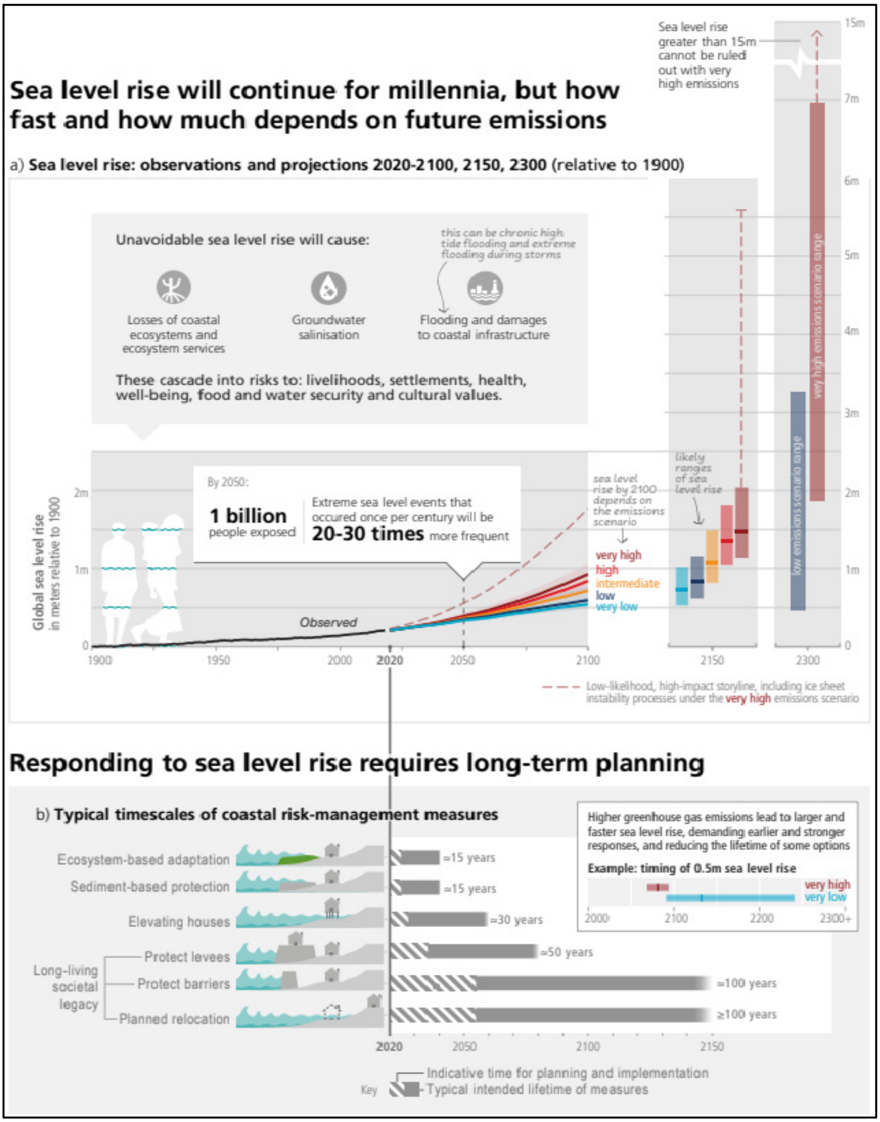

Figure 1 – Observed and projected global mean sea level change and its impacts, and time scales of coastal risk management. Source: [11].

Sea level rise, like other irreversible changes, will continue for thousands of years, at rates dependent on future emissions (Figure 2).

The consequences of climate change vary depending on the regions observed; although no part of the Earth is immune, scientists agree that Southern Europe is witnessing, and will continue to witness, more heatwaves, droughts, fires, coastal floods and windstorms, as well as periods of intense rainfall. In particular, most of these events occur during the summer, the most popular tourist season in the Mediterranean, with economic, social and, unfortunately, also disastrous outcomes on human health as dramatically happened in the summers of 2022 and 2023. In such a context, tourists' choices, which have always been linked to Mediterranean destinations, are starting to change.

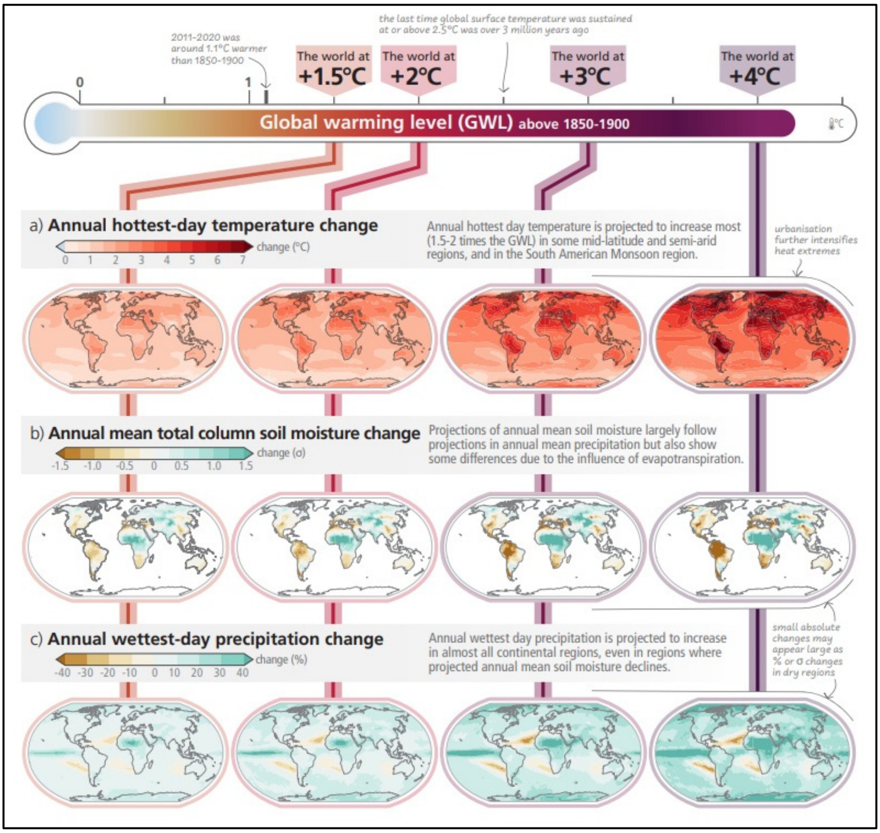

Figure 2 – Increase in global warming and regional changes in average climate. Source: [11].

3. Last Chance Tourism: current debates

In recent years, the surge in tourism driven by social media emphasizes that travel choices are increasingly shaped by the images of destinations shared on platforms like Instagram. This trend has enhanced the visibility of various places and their attractions, but it has also resulted in the creation of "must-see places" lists. Consequently, this can lead to an increase in visitors and potentially to overtourism, a situation where an excessive number of tourists negatively impact the destinations and the lives of local residents. Simultaneously, among the must-visit spots are those that might face extinction.

Last chance tourism (LCT), also referred to as extinction tourism [15], is a rapidly expanding niche market where tourists seek non-consumptive experiences with endangered animals and disappearing landscapes or seascapes. This type of tourism could significantly influence pro-environmental behaviour [16]. LCT is described as "tourism driven by the belief that certain places, people, or objects may soon cease to exist or be inaccessible, leading to a sense of impending loss" [5, p. 517]. To date, most LCT research has focused on recognizing it as a motivator for travel [2]. For instance, the primary motivation for most tourists visiting Churchill, Canada, to see polar bears was the species' noted vulnerability and "before they are gone", without understanding about how tourism and travel together to global climate changes contribute to this disappearing [3].

Two recent studies [7, 16] have confirmed the connection between last chance tourism (LCT) and tourists' pro-environmental behaviour in arctic regions. [16] examined boat-based polar bear viewing, and found that education and "environmental epiphany" were key predictors of tourists' intentions to engage in pro-environmental behaviour. Additional research is needed to apply these findings to non-polar LCT experiences to validate LCT as a strategy for preserving endangered destinations or species that could go extinct [8]. Moreover, comparing LCT destinations with other international and domestic locations is necessary to provide greater context and legitimacy to the findings [7].

Studies in Uluru-Kata Tjuta National Park, which hosts the renowned natural landmarks Uluru and Kata Tjuta - sacred sites for the local Indigenous people with distinctive geology - demonstrated that the less time available to visit a place, the stronger the motivation to travel there [17]. The decision, made in 2017 and finalized at the end of October 2019, to close the climb at Uluru, was also influenced by concerns about overtourism, safety, and the environmental impact of the activity. This indicates that the effects of last chance tourism often mirror those of overtourism, both increasing pressure on destinations due to higher visitor numbers. The issue of overtourism, which includes problems such as overcrowding, environmental damage, and cultural disruption, has been a significant concern for many destinations worldwide, leading to their closure or restricted access for tourists [19].

Last chance tourism often highlights the need for sustainable and responsible travel practices. Efforts to mitigate the threats to these coastal landscapes include implementing conservation measures, regulating tourist numbers, and encouraging eco-friendly tourism practices. It's crucial to balance the desire to experience these endangered destinations with the need to protect and preserve them for future generations.

A recent report by the European Travel Commission [4] confirms that Mediterranean countries remain the most popular destination for Europeans during the summer period. However, the number of European tourists has dropped by 10 % because many travelers, meanwhile, are shifting preferences to less hot periods. In fact, nearly 8 % of travelers specifically mentioned "extreme weather events" as their top concern. This decrease can be substantial in many areas, potentially becoming unsuitable for tourism under stringent warming.

4. The case-study: coastal erosion and Rotondella (Italy)

In the future, the way we travel will inevitably have to adapt to the consequences of climate change, as will the tourism sector: floods, heat waves, loss of biodiversity and coastal erosion are just some of the most impactful phenomena we are already witnessing today. The phenomenon of coastal erosion is a widespread process along the 8100 km of the Italian coast. In many Italian coastal municipalities, the retreat has affected more than 50% of the coastline in the last decade [10]. The southern coastal territory is most at risk; in particular Calabria with 60.9 %, Abruzzo 63%, Basilicata 57.7 %, Puglia 55 %, Campania 54.1 %, Molise 52.8 % (Figure 3).

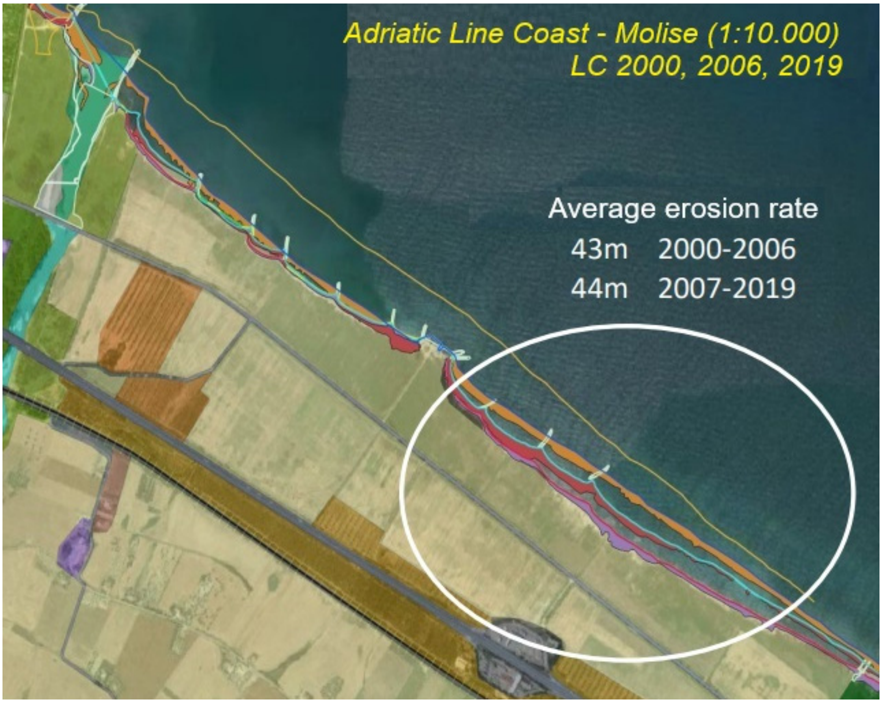

Figure 3 – Molise, example of a coastal area in severe retreat with the beach completely receding into the hinterland. Source: [9].

From 1970 to today, the stretches of Italian coastline subject to erosion have tripled with the disappearance of at least 40 million square meters of beaches. Effects linked in particular to the artificialization of the coastline and the use of land for port works and for various rigid protection structures such as the so-called breakwaters. *Basilicata* (and in particular the territory of *Rotondella*) is in first place as a percentage of eroding beach on the Ionian coast, but in Italy strong erosive processes are observed on the Tyrrhenian coasts (*Calabria*, *Campania*, *Liguria*, Tuscany and *Lazio*) and Adriatic coasts (*Emilia-Romagna*, *Molise*, *Puglia* and *Veneto*). Even in Sicily and Sardinia intense erosive processes affect large stretches of coastline. (Figure 4).

Figure 4 – Evidence of erosion processes on the Italian coasts. Source: [1].

According to the ISPRA report [9], coastal erosion is favored by a multitude of causes: geological, biological, anthropic and weather-climatic factors. Climate, in particular, is generally one of the main causes, but other factors can manifest themselves in each stretch of coast.

Climate change plays an important role in the erosion process due to the rise in sea levels globally and the intensification of extreme phenomena. The fact that the sea level is therefore already higher than in the past favors coastal flooding and further erosion of the coast. Among the 644 Italian coastal municipalities, those with high erosion rates are 54 that to date have seen their stretch of coast retreat by more than 50 % of the entire stretch of competence; there are 22 municipalities that have an exceedance of between 50 % and 60 % of the coast; there are 16 between 60 % and 70%, 8 between 70 % and 80 % and 7 between 80 % and 90 %.

An interesting case study is the coast in the municipality of *Rotondella* (on the Ionian Sea, in *Basilicata*) where this phenomenon is particularly marked. It is the only municipality characterized by widespread erosion along the entire coastal stretch.

Basilicata has a coastline of 70.4 km, divided between the Ionian and Tyrrhenian coasts (43 km and 27.4 km respectively), of which 27 % has been transformed by urban and infrastructural uses. 7.4 km have been transformed by port infrastructures, while 12.3 km are occupied by sparsely populated urban areas; 45 km of coast are natural, and 5.7 km can be considered agricultural landscapes. A characteristic of the Basilicata coast is that, unlike many other regions, there are no significant urban centers, which instead are historically found at a certain distance from the coast. With regard to the morphology of the coastline, there are 44 km of beach, 19 km of rocky coast, while 7.4 km of coast have been occupied by docks and fillings related to port uses [20].

From the data obtained from the Study of the *De Marchi* Commission, dated 1968, this stretch of low coast was not substantially eroded and, in many sections, there was an advancement of the shoreline. Twenty years later, of the 38 km of the Ionian coast, 28 were eroded (about 70 %). What happened is that between the end of the 1950s and the 1970s of the last centuries, artificial basins were built on 4 of the 5 rivers that affect the area (*Sinni, Agri*, *Basento* and *Bradano*), which retain an average of 5 million cubic meters/year of inert materials. Furthermore, in the period 1965-1977, at least 35 million cubic meters of aggregates were officially extracted from the alluvial areas of the aforementioned rivers, including a lot of sand.

There is no doubt that a sedimentary deficit of sand was created in the coastal area, with consequent strong retreat of the shoreline, which in long stretches retreated even 100-150 meters in front of the sea, affecting the coastal dunes and the forested areas behind them. In the province of *Matera*, the areas between *Policoro* and *Nova Siri* (to the south, where the municipality of *Rotondella* is located) and between *Scanzano Ionico* and *Lido di Metaponto* (to the north), are the most affected by erosion, with a retreat of up to 3 meters per year recorded over the last decade. In particular, in the *Lido di Metaponto* area, storm surges have caused a further retreat of the shoreline and caused significant structural damage as well as secondary effects of pollution of the freshwater aquifers serving a large area with a strong agricultural vocation [12, 13, 14].

Due to the physical nature of the two coastal stretches, the low coast of Metaponto is the most sensitive to possible erosion problems. From the data obtained from the De Marchi Commission Study, dated 1968, this stretch of low coast was not substantially eroded, and in many stretches, there was an advancement of the shoreline. Twenty years later, 28 of the 38 km of the Ionian coast were eroded (about 70 %). Between the end of the 1950s and the 1970s of the last centuries, artificial reservoirs were built on 4 of the 5 rivers that affect the area (*Sinni*, *Agri*, *Basento* and *Bradano*), which retain an average of 5 million cubic meters/year of inert materials. Furthermore, in the period 1965-1977, inert materials were officially extracted from the alluvial areas of the aforementioned rivers for at least 35 million cubic meters, including a lot of sand.

There is no doubt that a sedimentary deficit of sand has been created in the coastal area, with a consequent strong retreat of the shoreline, which in long stretches has retreated even 100-150 meters in front of the sea, affecting the coastal dunes and the forested areas behind them. In the province of Matera, the areas between *Policoro* and *Nova Siri* (to the south, where the municipality of *Rotondella* is located) and between *Scanzano Ionico* and *Lido di Metaponto* (to the north) are the most affected by erosion, with a retreat of up to 3 meters per year recorded over the last decade. In particular, in the *Lido di Metaponto* area, storm surges have caused a further retreat of the shoreline and caused significant structural damage as well as secondary effects of pollution of the freshwater aquifers serving a large area with a strong agricultural vocation [12, 13, 14].

Last chance tourism is able to attract tourists from all parts of the world, helping to accelerate these changes. Yet, last-chance tourism could represent a resource: visiting places subject to climate change could make people more aware of the situation and raise awareness of more sustainable lifestyles and behaviours. It is still early to establish whether the phenomenon of last chance tourism can really represent a resource in the fight against climate change or whether it will lead to an acceleration of the consequences. However, the rush to places at risk has now established itself on the world stage and attracts an ever-increasing number of tourists.

5. Conclusions

Post-Pandemic "revenge tourism" has been widely blamed for the surge, but the role of social media and tour operators cannot be denied. Ninety percent of tourists visit just ten percent of the world's 100 top destinations creating overtourism in famous destinations in contributing to the decline of these destinations. In numerous instances, the tourism industry seeks to increase visitor numbers and expand business opportunities before the destinations disappear [18].

Moreover, with the worsening conditions of climate change, certain destinations could certainly disappear, and this is undeniably a process that is getting worse. The problem is that visiting these "at-risk" places can hasten their demise. Since these destinations are damaged not only by tourism but also by other factors, it seems that the best way to protect them is to stop tourism. In this context, protests against tourism, especially overtourism, which have recently erupted at numerous European destinations, should be seen as promoting the preservation of these destinations. Peaceful ways of protesting should be directed more towards the authorities than towards tourists, who, although numerous, are not solely to blame. In addition to educational campaigns aimed at raising awareness about the environmental and cultural vulnerabilities of destinations, which should lead to more respectful tourist behaviors, destination management and marketing organizations will also need to take the lead in supporting initiatives such as the active demarketing of certain attractions [6].

Seeing to the case study, if the number of municipalities with high erosion rates appears limited, compared to a total number of 644 coastal municipalities, it should be considered that the percentages reported concern the entire coast of each municipality, also occupied by stretches that are not beaches and therefore cannot erode, such as stretches of rocky coast, river mouths and all human works. Furthermore, the percentages do not show a "natural" trend in coastal dynamics, but downstream of all the coastal defence works and nourishment carried out [10]. Currently, countries around the world have not fully developed a low-carbon tourism strategy, leaving it up to the sector to find ways to address climate change despite significant uncertainties. Furthermore, it is necessary to develop an effective strategy for the Integrated Planning and Management of coastal zones and the Blue Economy, which also includes adaptation and retreat programs, in order to be ready for the new scenarios induced by the ongoing climate changes. Additionally, the sector will not be affected uniformly; for instance, urban tourism will be less vulnerable compared to coastal tourism. Similarly, some parts of the world will be more sensitive to climate changes than others. Climate change also presents opportunities, as new regions and types of tourism become and have become attractive to tourists. However, these opportunities might be short-lived and overshadowed by negative impacts.

Acknowledgements

The work of Donatella Privitera was supported by the Italian Ministry of University and Research-National Recovery and Resilience Plan (NRRP). Award Number: Project code PE00000003, project title: ON Foods - Research and innovation network on food and nutrition, Sustainability, Safety and Security - Working ON Foods.

While the paper is the result of a joint work, sections 1, 3 and 5 are attributed to Donatella Privitera, sections 2 and 4 to Antonietta Ivona.

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VISIBILITY ANALYSIS IN WETLAND PROTECTION PROCESSES

Vito Martelliano, Nicoletta Denaro

Abstract: Wetlands are 'areas of high naturalness' essential for the survival of a large number of animal and plant species. The preservation of the biological diversity of wetlands is implemented through various protection regimes, such as parks, reserves, SCIs, SPAs and Ramsar sites.
However, in some cases, protection initiatives are insufficient in reducing anthropogenic pressures on wetlands threatened by the widespread urbanization and anthropization of the landscape, also their presence effectively affects, from a perceptive point of view, the landscape of wetlands.
The introduction of the perception analysis in wetland conservation processes could guarantee the integral protection of landscape. The visibility analysis method is based on the visual perception: intervisibility maps are created using GIS tools that measure how much a portion of land is visible from previously identified points, thus highlighting visual existing interactions between wetlands and the surrounding. The maps of the most visually exposed areas could be additional tools to protect wetland landscape, anticipating potential impacts on it. The proposed methodology has been applied to the case study of the southeastern Sicilian wetlands.

Keywords: landscape analysis, visibility analysis, GIS tools, wetlands protection

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

1. Introduction

The protection of the landscape heritage is implemented through the affixing of restrictions, the establishment of areas destined for protection and conservation of a natural, historic-cultural or archaeological context as well as the approval of landscape plans that, through a holistic approach, systemize the whole protection measures and regulations present in a territory.

In this context, the protection of a single asset, be it historical or natural, focuses more on the conservation of its physical integrity and less on the safeguarding of its relations with its context, i.e. with its users, uses, the elements of the landscape, the culture of the territory and society. Protection instruments aim to define more or less vast perimeters within which measures can be envisaged to protect the asset from the risks of improper and harmful uses. Often, an enclosure drawn on paper does not correspond to the signs of the territory demarcating instead a sharp transition from inside, where protection rules apply, and outside where they do not. To mitigate this transition, buffer zones characterized by an intermediate protection regime are introduced in order to produce a gradual transition between protected and unprotected areas. Nevertheless, the perceptive relations established by the protected property with the landscape context definitively escape the logic of enclosures. The gaze goes well beyond the constraining perimeters and unites the destiny of vast territories in an indissoluble bond [1].

The spread of GIS (Geographic Information System) tools, the creation of specific algorithms and the availability of increasingly accurate digital terrain models (DTM, DEM, DSM) has improved in recent decades thus refining the use of visibility analysis in the territorial and landscape field, and thus making it an essential tool for assessing the environmental impact of human interventions and, more generally, the identification of policies to protect the landscape heritage [1]. The result is the overcoming of the protection of the panorama in favour of a more general protection of perceptive relations and the identification of perceptive basins that constitute the reference areas for the definition of adequate safeguard measures.

The application of visibility analysis is widely used in the landscape field for the determination of the value of viewpoints and scenic routes [4]; on the contrary it is rarely used in highly natural systems. In natural areas, in fact, the study of physical and eco-systemic factors prevails over the perceptive one so that the resulting analytic-knowledge framework is only partially able to direct protection policies.

This paper aims to explore the concept of visibility in the context of wetland conservation, by analyzing the potential and limitations of this approach, and also by providing an example of its practical application in the context of south-eastern Sicily. Through the analysis of the proposed case study, we intend to demonstrate the importance of visibility consideration in the planning and sustainable management of wetlands in order to ensure the conservation of these precious ecosystems for the future generations.

2. Materials and methods

2.1 Wetland: values and threats

In comparison with other types of ecosystems, wetlands cover a relatively small area, approximately 6 % of the entire Earth's surface [10]. However, they represent some of the most important types of ecosystems in the world [5]: they are characterised by a very rich biodiversity, about the 40% of the world's species of plants and animals completely dependent on them [6], for that reason their conservation becomes a fundamental factor to guarantee biodiversity richness.

The life of many species of birds depends on wetland's network, especially during annual migrations: waterbirds rely on wetlands areas, they play a fundamental role in guaranteeing biological processes like breeding, wintering, and stop-hover [11].

Due to human activities, and also for natural effects, the total wetland surface in the world has been decreasing and the remaining has been deteriorating in quality to different degrees [2]. Over the last decades interest in wetland has increased and protection initiatives too, but widespread urbanisation, climate and land-use changes still threaten worldwide wetland habitat and waterbird species.

2.2. The wetlands of South-Eastern Sicily

Most of wetlands in Sicily are located on the slopes of the Iblei Mountains, along the coast of South-Eastern Sicily in the territories of Syracuse and Ragusa and involve four municipalities: Noto, Pachino, Portopalo di Capo Passero and Ispica (Figure 1).

Figure 1 – Geographical location.

The system of wetlands (Figure 2) hosts a huge number of animal and plant species and plays a strategic function especially by serving as stopover stations during the pre-post-reproductive migratory routes between Europe and Africa [3].

The current wetland system is characterised by a series of bodies of water that differ in shape, salinity gradient, extension and depth and are supplied by rainwater, sea water and partly by the aquifer [9].

The variation in the size of the bodies of water is regulated by the seasonal cycle; during summer months which are characterized by intense heat periods, most of the lake becomes considerably shrink or it completely dries up.

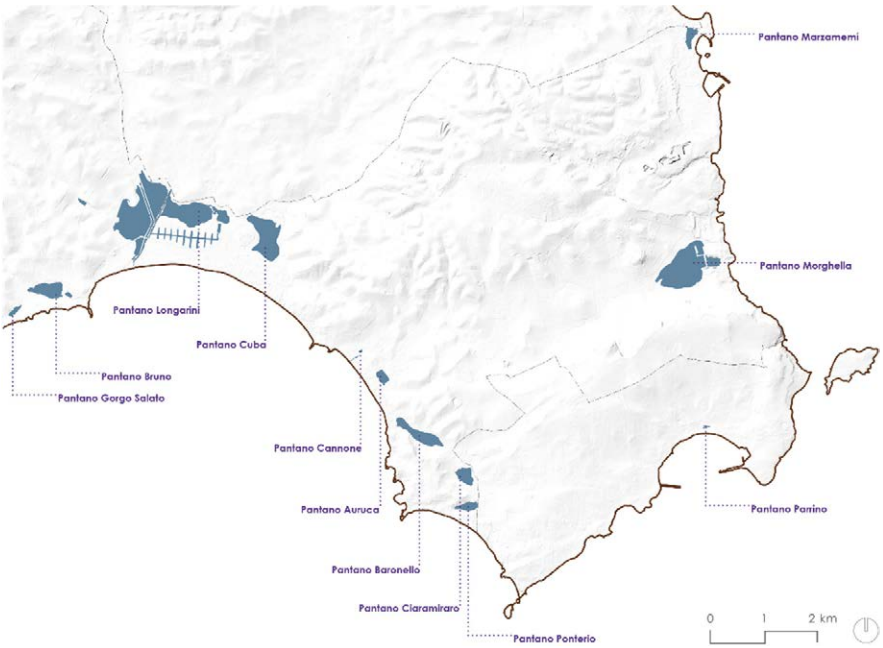

Figure 2 – South-eastern Sicily wetlands.

Since the second half of the 19th century, numerous wetland reclamation operations have reduced the wetland zones. Nevertheless, the high ecological importance of these areas continues to be seriously threatened by the anthropization of the territory. In particular, the construction along the coast and intensive greenhouse agriculture have a strong impact on wetlands.

Since the beginning of the 1970s protected horticulture has become widespread and the Sicilian South-Eastern coastal areas, due to their pedoclimatic characteristics, have been widely affected by these constructions that altered the traditional agricultural landscape thus reducing its quality [7].

Not only is the presence of greenhouses a visual detractor for the agricultural and wetlands landscape, but also it causes an effective imbalance in the natural ecosystem: reduces the lacustrine vegetation, exploits fertile soils and withdraws water for irrigation (figure 3). Pesticides and fertilisers full of nitrates, also threaten the wetlands [8], due to the permeability of the soil, pollute the water bodies thus causing an impoverishment of flora and fauna.

Finally, the plastic covers of the greenhouses creating the so-called 'lake effect', with direct impacts on the birdlife that swaps the greenhouses for water basins.

Figure 3 – Bird's-eye view of the Morghella water basin.

In order to protect current biodiversity and avoid further fragmentation, the wetlands are interested by national, regional and European protection programmes such as the Sicilian Ecological Network and the Natura 2000 Network. Yet, they have not been sufficient to prevent further anthropization and fragmentation of the landscape.

Analysis, protection and monitoring tools focus on achieving standards on wetland habitat quality thus overlooking the necessity of protecting the wetland landscape from a perceptive point of view. Uncontrolled land use of areas surrounding bodies of water modifies the entire perception of the wetland landscape by increasingly fragmenting it.

In this context, the introduction of an additional tool in the protection processes, such as the intervisibility maps, can contribute to the identification of perceived problems and help to protect the integrity of the wetland landscape.

2.3. Visibility analysis method

Thanks to the widespread use of GIS software visibility viewshed analysis have become easily accessible and workable. These methods are based on the quantification of which portions of landscapes could be seen from specific points of view, or otherwise the portion of lands whom seen specific points [1].

Usually, visibility analysis is used to calculate the portion of the landscape seen from privileged viewpoints or previously identified panoramic roads in order to monitor the impact of punctual elements such as new infrastructure or buildings on a specific observed view.

In the case of the integral landscape protection of natural elements such as wetlands, not only privileged viewpoints are selected but all potential viewpoints are identified by discretising the perimeter of water bodies into points at a constant distance of 30 m from each other (Figure 4).

Figure 4 – Outline of the wetland discretization process and definition of the maximum visual field extension.

To consider the variability in the extension of the water bodies that occurs with a reduction during the summer season, perimeters further inland than the main at a distance of 10, 20, 40 and 80 m. Other parameters concern the width and height of the visual range and the maximum depth of observation, coherently set.

The fundamental information source for processing the visibility analysis is the Digital Terrain Model (DTM), an elevation representation of the terrain using a grid of square cells; each cell contains the real correspondent height of the terrain. The resolution and accuracy of the spatial datum is variable and it characterises the quality of the visibility analysis: choosing the appropriate datum is crucial. For the visibility analysis of wetlands, a DTM was chosen that only has information on the ground surface without architectural constructs and vegetation. The use of DSM, Digital Surface Mode, was excluded because the altimetric information on the heights of buildings and vegetation in some cases distorts the results, for example vegetation is assimilated to an architectural building, without considering the transparency of the vegetated mass [1].

Furthermore, land cover may be subject to change over time, intervisibility maps using the DSM may represent a situation of transitory visibility so only the data containing the terrain information is taken as a baseline.

After processing between the extracted viewpoints and the DTM we obtain a raster file representing the associated viewshed, each pixel containing information on the number of points, so the number of times, from which that particular cell is viewed.

If we had considered only one point of view we would have obtained a binary raster (1 visible, 0 not visible), having n points, the values of the visible are sum up, in this way we can identify the most visually exposed areas (Figure 5).

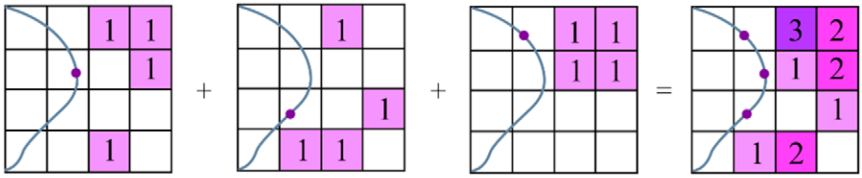

Figure 5 – Sum of viewshed considering multi points of view at the same time.

Results

The visibility analysis method was applied to the wetland of South-Eastern Sicily. First, the singular wetlands or groups of wetlands close to each other were discretized into points, which will constitute the observation points of the viewsheds (Figure 7). The inner perimeters were established at a distance of 10 m, 20 m, 40 m and 80 m from the most external one (Figure 6).

At this point, it has been defined all the parameters to simulate the perception of wetland from the surrounding: the observation point height is set at 0,5 m, the visibility radius at 5 km, that is the maximum observation distance in which contours and silhouettes can be distinguished in the landscape.

In terms of the source data 2x2 m DTM was used for this visibility analysis.

Once the data has been collected and all the required parameters have been set, the visibility analysis will be processed. The result is a single-band raster where the highest pixel value indicates the most visually exposed areas from/of wetlands (Figure 7). This process was carried out for all the observation points (in Figure 6) and at the end the pixel value where related to classes of visibility from very low visibility 1, to the very hight visibility 5. The last step that has been done was summing up all the visibility analysis in order to have a global map of visibility (Figure 8).

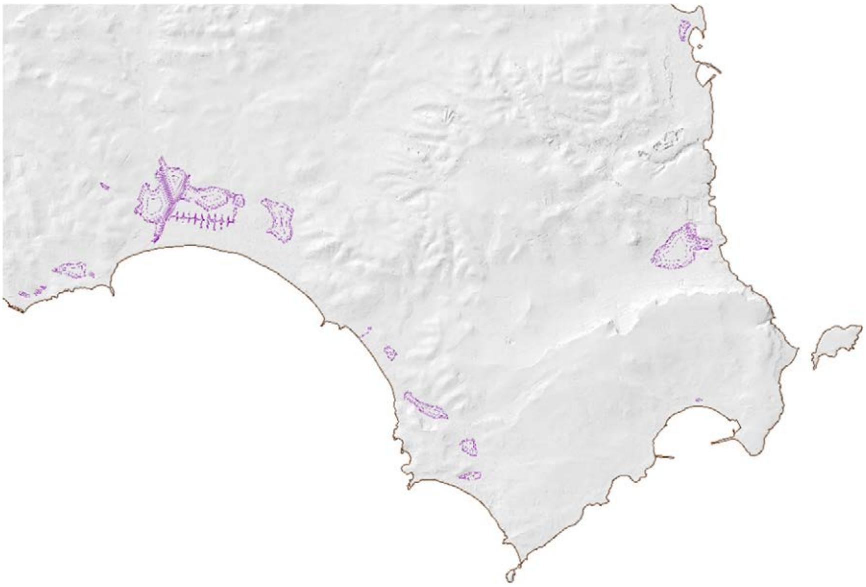

Figure 6 – Assumptions of more wetland perimeters as the seasons change.

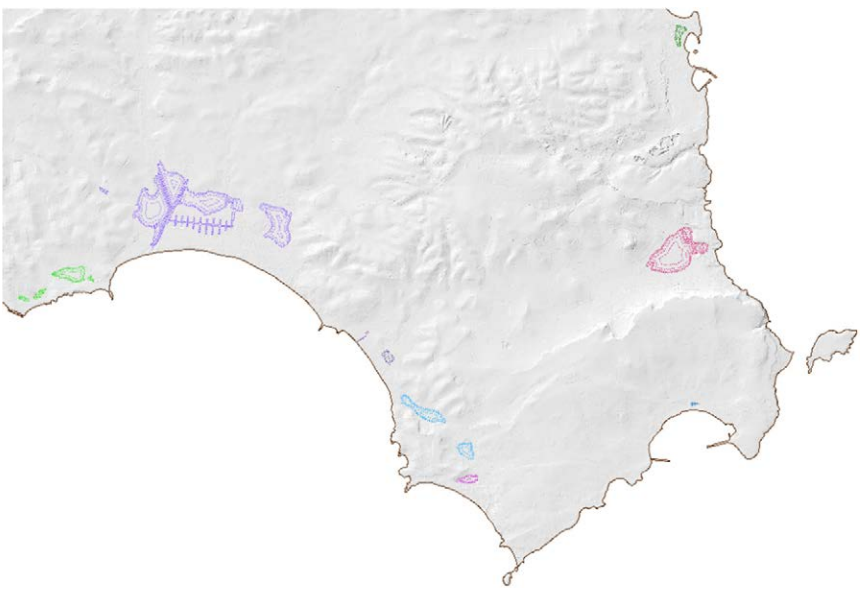

Figure 7 – Discretization of wetlands perimeters into points of observation.

Figure 8 – Map of visibility analysis for Morghella viewshed.

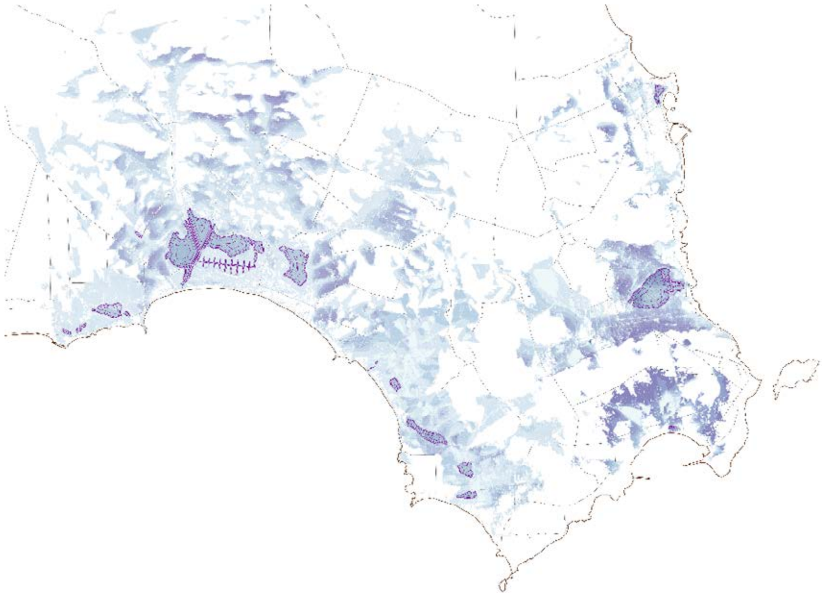

Figure 9 – Map of visibility analysis for the viewshed summed up.

Discussion

The landscape visibility analysis may be extremely useful in monitoring the effects that land use changes have on the visual perception of the wetland landscape.

The research employs a methodology for drafting an intervisibility basin for wetland complexes and, along with eco-system analysis, it proposes its use for the definition of a strategy of wetland protection. A strategy that defines wetland landscape made up of high natural value areas (i.e. wetlands and bordering areas), areas of ecosystemic interaction (i.e. areas that directly influence the ecosystemic conditions of wetlands) and areas of perceptual interaction.

The research demonstrates, then, that the wetland protection process cannot be said fully accomplished if, besides the protection of the physical and ecosystemic components, the perceptive component is not also pursued.

Visibility analysis is an effective complementary tool to safeguard wetlands and can be helpful in preserving their landscape integrity and defining more effective perimeter protection. It is even more true in the case of a complex of wetlands of territorial value whose perceptual basin is made up of all the perceptual basins of each wetland.

Conclusion

In this research, visibility analysis emerges as an innovative and interdisciplinary approach to understand and assess the visual relationships that wetlands establish with the bordering territorial context.

Through the use of GIS tools, it has been possible to integrate spatial data and perceptive analysis in order to identify areas of a highly perceptive interaction within which incoherent interventions can generate alterations in the high natural wetland ecosystem contexts.

The methodology proposed on a vast territory for the perceptual analysis of a naturalistic context made up of several wetlands allows, through the qualitative identification of the visibility basin of the wetland system, to influence decision-making processes and protection policies through the definition of a protection area not exclusively linked to ecosystem aspects.

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SEA LEVEL RISE PROJECTIONS: RISK AND IMPACTS ON POPULATIONS IN THE MEDITERRANEAN BASIN

Federico Martellozzo, Filippo Randelli, Matteo Dalle Vaglie, Carolina Falaguasta

Abstract: Extreme Sea Level Rise (ESLR) refers to the significant elevation in ocean levels driven by climate change and other anthropogenic and geophysical factors. This phenomenon poses a substantial threat to coastal populations, particularly as climate change accelerates the rate of sea level rise. Reducing greenhouse gas emissions and addressing climate change causes are essential to slowing ESLR and minimizing its impacts on coastal communities. However, achieving significant global reductions in GHG emissions is a complex, long-term endeavour. As a result, many coastal regions, and even some inland areas, will inevitably face the impacts of ESLR sooner or later, with certain areas being more vulnerable due to their land use and topography. Currently, numerous institutions have modelled ocean volume expansion at various geographical scales. However, to the best of our knowledge, a spatially explicit, detailed map illustrating the potential impacts of ESLR on the European population is not freely available. This study aims to create geographically detailed datasets that depict the inland extent of ESLR impacts under future climate change conditions, focusing on the Atlantic coast of Europe and the Euro-Mediterranean basin. By integrating ESLR projections under IPCC 4.5 and 8.5 scenarios, our estimates reveal that ESLR poses a significant threat to coastal populations. The data indicates that, on average, the potential impact on human settlements is substantial. The study identifies that between 2050 and 2100, ESLR could affect areas where millions reside, emphasizing the urgent need for adaptive strategies to protect vulnerable populations and mitigate the adverse effects of rising sea levels.

Keywords: Extreme Sea Level Rise

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Federico Martellozzo, Filippo Randelli, Matteo Dalle Vaglie, Carolina Falaguasta, *Sea level rise projections: risk and impacts on populations in the mediterranean basin*, pp. 420-428, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.38

Introduction

Sea level rise (SLR) represents a critical challenge for coastal populations, driven primarily by the melting of land-based ice and the thermal expansion of seawater due to global warming. Human activities, such as fossil fuel combustion and deforestation, have significantly accelerated SLR, leading to an increase of approximately 20 cm in global average sea levels since 1880 [1]. This acceleration underscores the urgent need for monitoring and addressing SLR due to its profound implications for coastal communities and infrastructure [2; 3].

The impacts of SLR are particularly severe in low-lying and densely populated coastal regions. Cities such as Miami, New York City, and Shanghai are highly susceptible to increased flooding and erosion, which can damage homes, businesses, and critical infrastructure like airports, ports, and transportation networks [4; 5]. River deltas, including the Nile Delta and the Ganges-Brahmaputra Delta, face the dual threats of flooding and saltwater intrusion, which can lead to significant economic and social disruptions [6].

Adaptation measures, such as constructing sea walls, elevating buildings, and establishing natural barriers, are being implemented to mitigate these impacts. However, reducing greenhouse gas emissions remains vital for slowing the progression of SLR and protecting coastal communities in the long term. The interaction between SLR and the increasing frequency and intensity of storms due to climate change further exacerbates these risks, resulting in more destructive storm surges and accelerated coastal erosion [7].

This study aims to evaluate the impact of Extreme Sea Level Rise (ESLR) on coastal populations in Europe, with a focus on the Atlantic coast and the Euro-Mediterranean basin. By utilizing projections from the IPCC scenarios 4.5 and 8.5, this research seeks to create comprehensive and geographically detailed datasets that delineate the potential future impacts of ESLR under various climate change conditions. The goal is to provide a nuanced understanding of the vulnerability and resilience of coastal populations, thereby informing the development of effective adaptation and mitigation strategies to protect human settlements from the threats posed by rising sea levels.

Methods and Data

Data Collection and Selection - This study utilizes sea level rise scenarios provided by the Joint Research Center (JRC), based on climate models and projections from [8]. These scenarios account for factors such as global warming, glacier melting, and ocean thermal expansion. For our analysis, we used Extreme Sea Level Rise (ESLR) data under the IPCC RCP 4.5 and RCP 8.5 scenarios, projecting impacts up to 2050 and 2100 for the Mediterranean basin and the Atlantic coast of Europe.

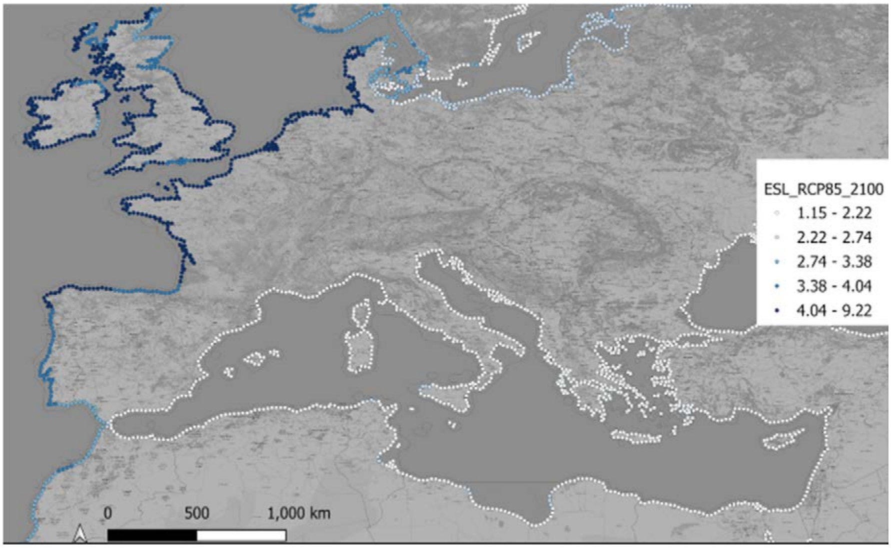

Figure 1 - Variance and location of JRC ESLR projections for the Mediterranean basin and the North Atlantic coast of Europe.

Thiessen Polygon Tessellation - To map the impact of ESLR, we implemented a Thiessen polygon (Voronoi diagram) tessellation, which divides the region into contiguous areas based on proximity to a set of source points. In this case, the source points are coastal locations with JRC ESLR projections. This method provides a detailed spatial representation of tidal elevation distribution. A Digital Terrain Elevation Data (DTED) from the USGS with a resolution of approximately 30 meters was used to generate these polygons, enabling the spatial association of inland pixels with the closest ESLR forecast values. This approach allows for precise comparison of projected ESLR values with current elevations along the coast.

Quantifying Uncertainty and Vulnerability - The JRC provides three ESLR projection values for each sample point: a conservative estimate (5th percentile), a median estimate (50th percentile), and a severe estimate (95th percentile). These values represent the uncertainty in the model outputs. We use this uncertainty as a proxy for vulnerability, generating spatial maps that indicate the likelihood of regions being impacted by ESLR. This approach aligns with risk assessment literature [9; 10; 11; 12], illustrating that more severe estimates, while broader in impact, are less probable and therefore represent lower risk. Conversely, conservative estimates, being more likely, indicate higher vulnerability. It is essential to recognize that vulnerability in this context is primarily derived from geophysical properties rather than the interplay of social and physical factors.

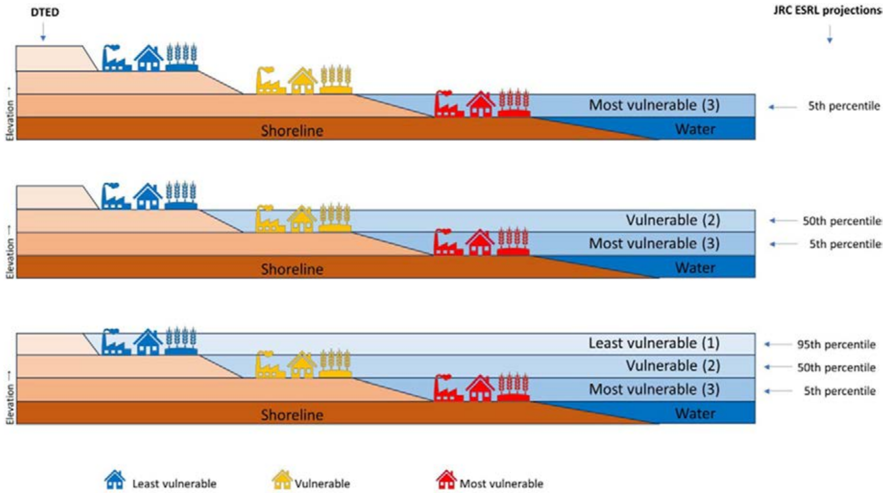

Figure 2 - Diagram illustrating the rationale for characterizing land vulnerability through ESLR projection uncertainty.

Filtering False Positives - To refine our results, we implemented a filtering approach based on the Bathtub-Based Inundation rationale [13]. This method addresses the potential inclusion of false positives, such as inland depressions below sea level without hydrological connection to open waters. We overlaid initial ESLR impact maps with the geographical extent of persistent water bodies (using data from Copernicus EU-Hydro and global HydroSheds) to ensure spatial contiguity. Pixels contiguous with permanent inland water bodies and coastlines were retained, while isolated pixels without hydrological continuity were excluded. This filtering, repeated until no differences were observed, was critical for accurately representing areas at risk of submersion under IPCC. scenarios RCP 8.5 and 4.5 up to 2050 and 2100, eliminating erroneous inclusions (Fig. 3). scenarios RCP 8.5 and 4.5 up to 2050 and 2100, eliminating erroneous inclusions (Fig. 3).

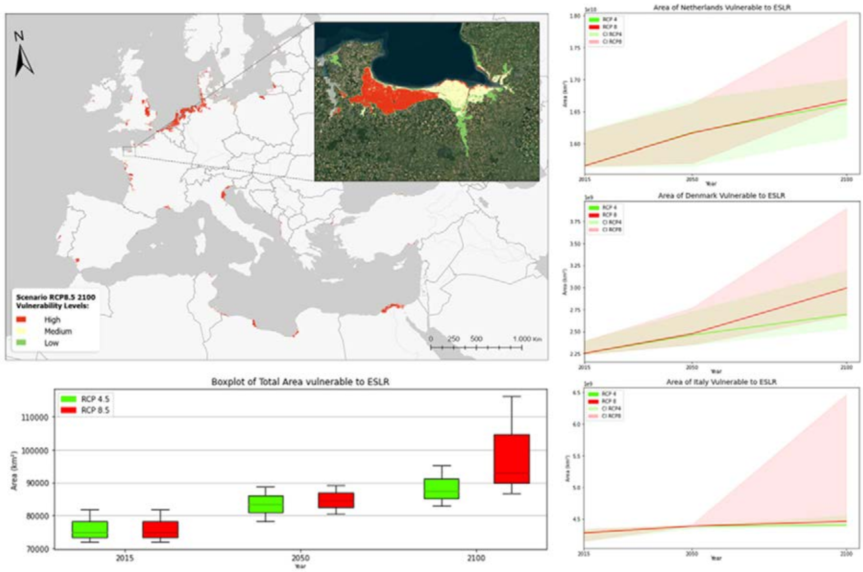

Figure 3 - Final filtered maps showing regions likely to be impacted by ESLR, excluding false positives.

Estimating Population Impact and Vulnerability Due to ESLR - In alignment with similar studies in the literature, we estimated the potential impacts of Extreme Sea Level Rise (ESLR) on populations by maintaining a consistent assumption: current population distributions and associated socioeconomic values remain constant into the future. This study utilized population data from the GHSL Copernicus Programme to evaluate the magnitude of potential impacts on populations within various land-use classes. Our methodology involved overlaying future ESLR projections onto current population distribution maps to identify areas at risk and assess the cumulative impact within each scenario. The analysis was divided into two main components.

Results of Population Impact of ESLR

The analysis identifies significant variations in projected population impacts due to Extreme Sea Level Rise (ESLR) under different scenarios (RCP 4.5 and RCP 8.5) and timeframes (2050 and 2100). Population data from the GHSL Copernicus Programme was utilized to assess exposure across various European and neighboring countries.

Baseline Scenario - Currently, countries such as Egypt, the Netherlands, and the United Kingdom have the highest populations at risk, with millions of people potentially affected (fig. 4).

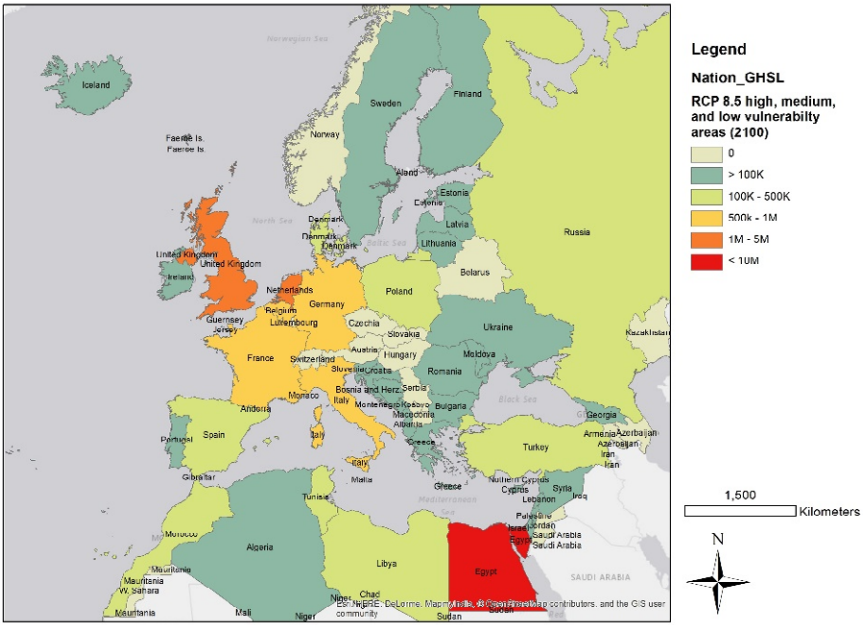

Figure 4 - Population impacted by ESLR in 2100 under RCP 8.5 scenario considering areas under high medium and low vulnerability.

RCP 4.5 Projections (2050 and 2100): if focusing exclusively on the highly vulnerable areas by 2050 (thus the smaller spatial extent of impacted land), Egypt's population at risk sets at around 4.3 million, while Spain having approximately 170 000. By 2100, Egypt’s at-risk population remains similar, while Spain's increases to around 180 000. If we include also medium vulnerability areas Spain's population remains more or less stable at 170 000 both in 2050 and (slightly) increasing further by 2100. By extending the analysis also to low vulnerability areas similar trends are shown for the populations at risk, with Spain's impacted population topping to approximately 200 000 by 2050 and slightly higher by 2100, whereas. Egypt is somewhat stable through all the RCP 4.5 analysis.

RCP 8.5 Projections (2050 and 2100): regarding RCP 8.5 scenario in high vulnerability areas by 2050 Egypt's population at risk is foreseen to still remaining around 4.3 million, while Spain's population settling at approximately 180 000. By 2100, Egypt’s impacted population soars to around 7.4 million, with Spain's reaching about 350 000. If including also the medium vulnerability area, Spain's population at risk increases steadily, reflecting the broader impact under more severe climate scenarios. Expanding the analysis to areas with low vulnerability shows similar trends, with significant increases in populations at risk, especially by 2100, where Egypt’s affected population also rises dramatically.

Besides, all the Netherlands shows consistently high numbers of affected populations, with projections reaching up to approximately 4.7 million people under the most severe scenario by 2100. In the UK significant impacts are foreseen, with up to around 1.8 million people at risk under the severe scenario by 2100, whereas Germany's impacted population could reach up to about 880 000 people under the severe scenario by 2100.

The projections indicate a considerable increase in the population at risk from ESLR under both RCP 4.5 and RCP 8.5 scenarios, with more severe impacts observed under RCP 8.5. The highest impacts are noted in Egypt, the Netherlands, and the United Kingdom, underscoring the urgent need for targeted adaptation and mitigation strategies. These findings highlight the importance of incorporating ESLR projections into coastal planning and policy-making to protect vulnerable populations and enhance resilience.

Discussion

The projections of Extreme Sea Level Rise (ESLR) and their associated impacts on populations hold profound policy, economic, and social implications. If these projections are realized, the consequences could be substantial and far-reaching, necessitating comprehensive and multifaceted intervention strategies. From a policy perspective, the integration of ESLR projections into coastal zone management becomes critical. Policymakers must prioritize the updating of urban planning frameworks, zoning laws, and infrastructure development guidelines to effectively mitigate future risks. This involves not only the construction of physical sea defenses but also the restoration of natural barriers such as mangroves and wetlands, and the design of resilient infrastructure capable of withstanding rising sea levels. The findings underscore the urgency of global climate action, emphasizing the necessity for stronger commitments to reduce greenhouse gas emissions to slow the progression of sea level rise and mitigate its impacts on coastal communities.

Economically, protecting critical infrastructure from ESLR will demand substantial investment. This encompasses both the upgrading of existing infrastructure, and the construction of new, resilient structures designed to endure the effects of rising sea levels. The increased risk of flooding and damage in coastal areas will likely lead to higher insurance premiums, reflecting the greater exposure to ESLR. Moreover, the potential displacement of large populations from vulnerable coastal areas could result in significant economic impacts, including the loss of property values, increased unemployment, and economic strain on areas that accommodate displaced populations.

Socially, large-scale displacement due to ESLR poses considerable challenges. Housing shortages, increased pressure on urban services, and potential conflicts over resources in areas that receive displaced populations are likely outcomes. The stress and uncertainty associated with displacement and the threat of flooding can adversely affect the mental health and overall well-being of affected populations. Furthermore, communities that have resided in coastal areas for generations may face the loss of cultural heritage and social cohesion if forced to relocate due to ESLR.

While this study provides valuable insights into the potential impacts of ESLR, several limitations must be acknowledged. The projections are based on population data and sea level rise models that may not capture local variations at a finer scale. This could lead to underestimations or overestimations of impacted populations in specific areas. The study relies on RCP 4.5 and RCP 8.5 scenarios, which are based on specific assumptions about future greenhouse gas emissions. Changes in global policies or unforeseen technological advancements could alter these trajectories, affecting the accuracy of the projections. Furthermore, the analysis primarily focuses on sea level rise and does not account for other climate change-related factors, such as increased frequency and intensity of storms, which could exacerbate the impacts on coastal populations.

In conclusion, the study underscores the urgent need for targeted policy measures, significant economic investment, and comprehensive social strategies to mitigate the potential impacts of ESLR on vulnerable coastal populations. Future research should aim to refine data resolution, incorporate additional climate variables, and explore adaptive strategies to enhance community resilience. This comprehensive approach will be essential to safeguarding populations and infrastructure in the face of rising sea levels and ensuring sustainable development in coastal regions.

Conclusion and Key Findings

This study highlights the significant potential impacts of Extreme Sea Level Rise (ESLR) on populations in Europe and neighboring regions under various climate scenarios. Key findings include:

1. High-Risk Areas: Countries such as Egypt, the Netherlands, and the United Kingdom are identified as having the highest populations at risk, with millions potentially affected by 2100 under severe scenarios.
2. Scenario Projections: Under the RCP 8.5 scenario, the population impact is substantially greater, underscoring the importance of strong climate action to mitigate these effects.
3. Policy and Economic Implications: The study underscores the need for comprehensive policy measures, substantial economic investments in resilient infrastructure, and social strategies to address potential displacement and health impacts.

These findings highlight the urgency for integrating ESLR projections into coastal planning and policy-making, emphasizing the necessity for proactive adaptation and mitigation strategies to protect vulnerable populations and enhance resilience against future sea level rise.

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THE EUROPEAN CHARTER FOR SUSTAINABLE TOURISM (ECST) AS A MODEL OF BEST PRACTICES AND PARTICIPATORY GOVERNANCE. THE CASE STUDY OF THE ASINARA NATIONAL PARK

Mario Gesuino Masia, Vittorio Gazale, Sonia Malvica, Nicoletta Pinna, Donatella Carboni

Abstract: The European Charter for Sustainable Tourism (ECST) represents a voluntary management tool for protected areas that promotes the implementation of sustainable tourism for both the environment and local communities, as well as for all the stakeholders (e.g., firms, tourists); its principles emerge as an essential guide for designing policies respecting the environment and actively involving the local community. The present work focuses on the Asinara National Park (Porto Torres, Sardinia-Italy) as a case study of the ongoing application of the ECST (i.e., renewal phase of Phase I and initiation of Phase II). The aims were: (1) to identify the strengths and weaknesses related to confirming Phase I; (2) to isolate the motivations leading a firm to obtain the ECST certificate. Through a methodology involving official documentation analysis and the Park's entrepreneurial landscape, results suggested a systemic vision of stakeholder engagement in creating a model for best practices to qualify the socio-economic network. Promoting participatory and inclusive governance could ensure a balance between sustainable tourism and environmental conservation on the Asinara island.

Keywords: Protected Areas; Governance; ECST, Stakeholder; Asinara.

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Mario Gesuino Masia, Vittorio Gazale, Sonia Malvica, Nicoletta Pinna, Donatella Carboni, *The European Charter for Sustainable Tourism (ECST) as a model of best practices and participatory governance. The case study of the Asinara National Park*, pp. 429-439, DOI: 10.36253/979-12-215-0556-6.39

1. Introduction

Recent irreversible changes to the ecosystem [1; 2] led to the identification of effective environmental protection strategies [3; 4]: accordingly, certifications (i.e., certificates with international validity) attest compliance with specific criteria for environment management. The attention to sustainability and respect for the environment promoted by the 2030 Agenda [5] translates into the conservation of natural ecosystems and biodiversity, reflecting a global commitment towards more responsible practices. In Italy, the System of Protected Natural Areas and Parks was introduced with Law 394/91, which defined their classification and established the official list; nature conservation is also intended as an ever-increasing number of people interacting with it in harmony [6]. In Italy, there are 25 national parks [7] and 2646 sites belonging to the Natura 2000 (on December 2023), which is identified by the Italian Regions as an ecological network spread across the entire territory of the European Union aiming at guaranteeing the long-term survival of the most threatened species and habitats [8]. In particular, it can be distinguished 2364 Sites of Community Importance (SCI), 2302 of which have been designated as Special Conservation Areas, and 643 Special Protection Areas (SPAs), 361 of which are type C sites, i.e. SPAs coinciding with SCI/SAC [9].

European laws support the protection of the ecosystem and high-quality services within the protected areas. Such a quality represents a key element of competition and competition, as well as ethical incentives [10; 11]. The certifications are produced by an organism independent from the applicant and constitutes the final result of a procedure, which aims to verify whether a product, a process, a system or an organization meets certain specifications [10; 12].

Among the numerous certifications present today in various sectors, quality brands play a crucial role in reducing the environmental impact of products and services [13]: assigned based on a system of selective criteria, they attest that the practices adopted by operating companies in protected areas are sustainable and eco-friendly [10]. The European Charter for Sustainable Tourism (ECST) stands out among the European certifications, as it promotes a working method based on partnership and the sharing of fundamental principles. The heart of the Charter lies in the collaboration between all interested parties, whether public or private. Through a participatory process, these parties create a forum or an equivalent body and, in collaboration with the park, develop a common strategy and a five-year action plan that is shared, co-responsible, and renewable [14].

The Asinara National Park is included within Sardinia's Network of Parks and Protected Areas established in 2002 and represents a site of extraordinary beauty and ecological and cultural value [15; 16; 17], whose sustainable development is a priority not only for local communities but also for the national and international scene [18]. The Park affects a vast area, including all the municipalities in the gulf of the same name [19]. The Asinara Park owns the ECST, which allows the granting of the Environmental Quality Mark of the Asinara National Park to requesting firms [20] and contribute to the improvement of environmental quality in the territory [21]. It also promotes partnerships between the various stakeholders to create a tourist offer compatible with protecting and safeguarding natural heritage [23; 24]. Its adoption represents a fundamental step to ensure that tourism activities in the Park are managed in such a way as to preserve and enhance this unique heritage [25].

However, ECST certification alone is insufficient to guarantee sustainable tourism, economic growth and environmental protection: collaboration between stakeholders (i.e., businesses) is pivotal, combining the best resources of the territory in a coordinated initiative with a medium-long strategy [14]. To paint a clear picture of lessons learned and aspects that need improvement, active participation and involvement of stakeholders are crucial for the success of the certification process and the long-term sustainability of tourism initiatives within the ECST. Analyzing their motivations, expectations, and concerns helps make practical recommendations to facilitate and promote their engagement. Considering the case study of the Asinara National Park [25], the aims of the present study were: (1) To identify the strengths and weaknesses related to confirming Phase I; (2) To analyze the motivations leading an enterprise to obtain the ECST certification.

2. The European Charter for Sustainable Tourism (ECST)

The Action Plan developed by each Protected Area in Phase I of the ECST follows ten key themes [28]: Protect valuable landscapes, biodiversity and cultural heritage; Support conservation through tourism; Reduce carbon dioxide emissions, pollution and waste of resources; Ensure safe accessibility, quality services and unique experiences for all visitors; Communicate the area to visitors effectively; Guarantee social cohesion; Improve the well-being of the local community; Provide training and strengthen skills (capacity building); Monitor tourism performance and impacts; Communicate actions and commit to the Charter [28]. Adherence to the ECST is divided into three sequential phases: (1) Phase I, directed to European Protected Areas and local stakeholders to develop an Action Plan for sustainable tourism; (2) Phase II, which is a certification for local operators; (3) Phase III, for tour operators. The Asinara National Park (Sardinia) started the ECST process in 2019 and was approved in 2020.

The protected area is therefore required to create and manage forums and working tables with the various players in the tourism sector, create a diagnostic report that includes an analysis of the tourism market in the area, the strategies already in place, the opportunities and impacts of tourism from an environmental, economic and social point of view. Together with the Forum, the protected area then develops a final Strategy and Action Plan document, which includes specific actions of the park and the other actors of the Forum. This document must obtain a positive evaluation from EUROPARC, which subsequently awards the Diploma of the European Charter for Sustainable Tourism in Protected Areas. Once recognition has been obtained, the protected area and all the actors involved must implement the Action Plan in a co-responsibility relationship. Furthermore, the method can further deepen relations between the park authority, local operators and tour operators through bilateral cooperation agreements and mutual support.

The ECST network has experienced significant growth, now comprising 87 sustainable destinations from 12 countries. This network involves a wide range of stakeholders, including local tourism businesses, local and regional government authorities, NGOs, and many others. In Italy, the network includes 21 National Parks, 16 Regional Parks, 4 Marine Protected Areas, and 4 other areas. Notably, 7

National Parks, 5 Regional Parks, 1 MPA (joining in 2021), and 1 other area (joining in 2021) are actively participating in Phase II. Among these, the Asinara National Park is a key participant.

3. Materials and Methods

3.1. The case study of Asinara National Park

The Asinara National Park (Porto Torres, Italy) formally initiated the process of joining the ECST in 2019, achieving the first Phase I certification in 2020. In June 2023, the Park officially commenced Phase II of the ECST, a path approved by Federparchi and ratified with a resolution in November 2022. The primary objective of this phase is to offer companies operating in the Park the opportunity to obtain ECST certification. This initiative, promoting a shared path of environmental sustainability under the aegis of the EUROPARC Federation, underscores the Park's unwavering commitment to environmental preservation. The Park is currently in the process of renewing Phase I and implementing Phase II, further solidifying its dedication to sustainability.

About Asinara's entrepreneurial landscape distributed and operating in the Park Vast Area (Figure 1), 24 % offer Park Visit Services, on foot, by bicycle, by off-road vehicle, tourist train and bus, representing the largest category; 22 % own sailing pleasure craft (charter); 14% offer motorboat services (internal combustion engine); 12 % deal with fishing tourism; 8 % are involved in transportation services (tourist transport, Stintino - Asinara route); 6 % are dedicated to catering and accommodation services; 4 % own electric motor pleasure craft or organize underwater guided tours; 2 % are engaged in Park-brand craft activities and services or offer bicycle and electric vehicle rental services; 1 % deals with mooring field services or with public transport (territorial continuity from Porto Torres to Cala Reale - Asinara Island).

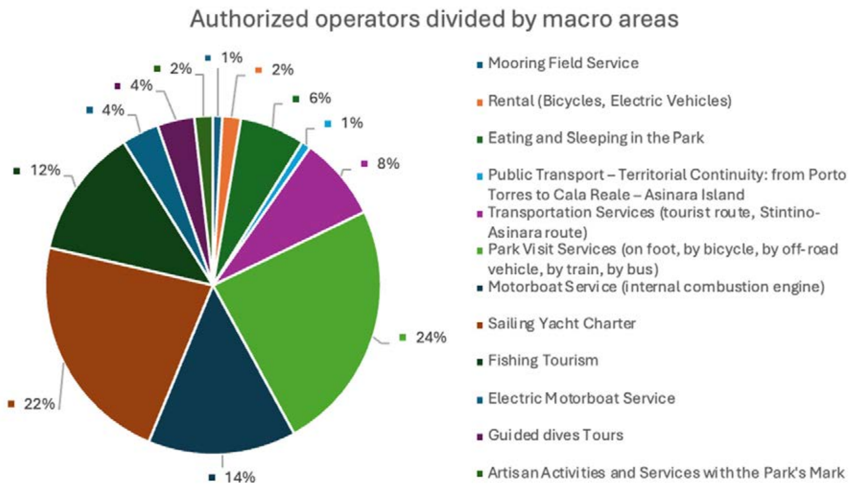

Figure 1 – Authorized firms of the Asinara National Park and Marine Protected Area, year 2024. Source: Authors' elaboration from Asinara National Park.

Some of the firms have certifications, i.e., the ECST or Park and Protected Areas Network Quality Label (Figure 2). Considering the economic activity code (i.e., Ateco), the 29 % of certified operators offer Park Visit Services, on foot, by bicycle, with off-road vehicles, trains and buses, representing the largest category (Ateco 77.11; 77.21; 77.39; 49.31; 49.32; 49.39; 79.9; 50.1; 52.22); 25 % own sailing pleasure craft (charter) (Ateco 50.1; 52.22; 55.20.51; 77.21; 77.34; 85.32.01; 85.51); 12 % offer motorboat services (internal combustion engine), (Ateco 13.92.2; 50.1; 55.1; 79.90.2; 49.32.2; 49.39.09; 77.21.02; 47.19.9; 47.64.1; 47.78.32); 10 % are involved in transportation services (tourist transport, Stintino - Asinara route) (Ateco 79.9; 50.1; 52.22; 49.31; 77.21); 7 % own electric motor pleasure craft (Ateco 50.1); 5 % organize underwater guided tours (Ateco 85.51; 93.11; 93.29.9); 3 % are engaged in craft activities and services that use the Park brand (Ateco 52.29.21; 52.22.09); 2 % deal with mooring field services (Ateco 52.22) or offer bicycle and electric vehicle rental services (Ateco 52.22). There are no certified operators dedicated to catering and accommodation services (Ateco 55; 56) or deals with public transport (territorial continuity from Porto Torres to Cala Reale - Asinara Island) (Ateco 50).

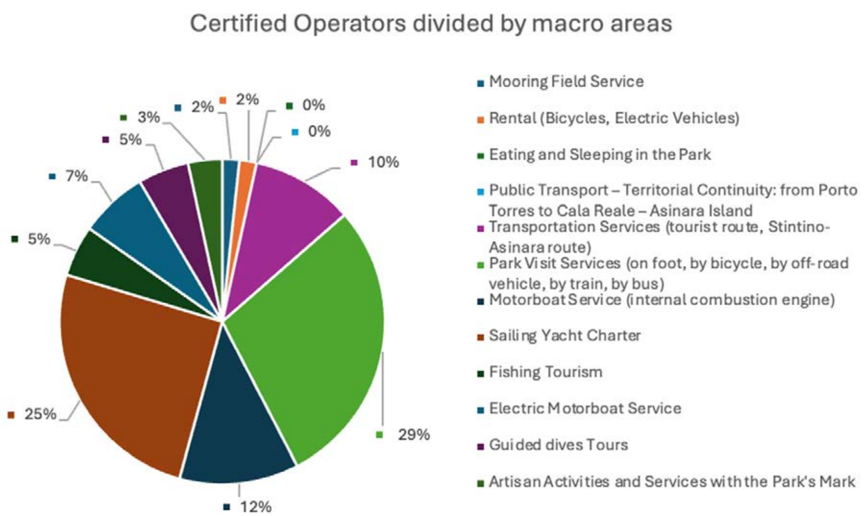

Figure 2 – Certified firms of the Asinara National Park and Marine Protected Area, year 2024. Source: Authors’ elaboration from Asinara National Park.

3.2. Asinara’s ECST Application

The official documentation produced by the EUROPARC Federation, and the Asinara National Park was analysed to identify strengths, weaknesses, and best practices, focusing mainly on the Verifier Evaluation Report drawn up by a representative of EUROPARC during the Park accreditation. The report comprises five sections: A) General information; B) Sustainable tourism FORUM; C) Sustainable tourism strategy and action plan; D) Addressing the key topics; E)

Experience and final comments. The evaluation expressed by the Verifier is on an X-3* scale where X corresponds to an irrelevant action and 3* to an excellent one, considered as best practice. To identify the best practices and the pros and cons linked to the renewal of Phase I of the CETS, the evaluations with a score of 3-3* were considered as pro / best practices due to their effectiveness, while an evaluation of X-0-1 represented deficient points.

3.3. Stakeholders' perception of ECST-related benefits and issues

An online ad hoc Google Forms-hosted questionnaire was used to investigate entrepreneurial stakeholders' perception of ECST (Table 1). Data collection took place in May 2024. Inclusion criteria required participants to be aged 18 years, to represent an entrepreneurial reality operating in the Gulf of Asinara, to be already certified with the Park and Protected Areas Network Quality Label, and to possess the ECST certification/desire to obtain it in the future. Overall, 16 entrepreneurial stakeholders took part in the study. Before starting the questionnaire, participants were required to read a brief overview of the study, and then they were asked if they would like to continue, thereby implying consent. After giving consent, participants were directed to the first section to provide ratings for 9 ECST-related benefits (i.e., BE items). A Likert-type scale ranging from "Totally disagree" (1) to "Totally agree" (5) was used for responses. Then, the ECST-related issues (i.e., IS items) were investigated through a six item-scale to evaluate the level of difficulty perceived by firms to obtain the ECST certification; the same Likert-type scale already used for BE was also provided. The last questionnaire session allowed participants to insert the enterprise's general information. Finally, participants were debriefed. The study was conducted in accordance with the Italian Psychological Society code of ethics.

Table 1 – Recovery rate and percentage of displaced tracers after the first (6 h) and second (24 h) surveys at Barbarossa beach as a function of the injection position of the pebbles.

General information	ECST-related benefits	ECST-related issues (scale)
Category of work activity Certifications (i.e, Park and Protected Areas Network Quality Label; ECST)	BE1. Greater visibility BE2. International recognition BE3. Marketing strategy BE4. Sustainability BE5. Building business networks BE6. Improvement of the tourist offer BE7. Access to training courses BE8. Support for the local economy BE9. New business opportunity	IS1. The entry requirements are excessive IS2. The entry requirements require too high and/or specific skills IS3. The bureaucratic requirements are excessive IS4. The forms are very understandable (R) IS5. Keeping requirements met over time requires considerable effort IS6. Internal monitoring demands take up excessive time and energy from the company

Note. (R) = reversed item.

4. Results and Discussion

4.1. ECST Application

From the analyzes conducted on the documentation relating to the renewal of Phase I and from the evaluation reports drawn up by EUROPARC Federation during the ECST membership process, the following points emerged:

- *Strenghts*: (1) Consistency and continuity: Actions and projects are in line with the park's past and present policies, contributing to conservation and sustainable development; (2) Planning and financing: Strong planning and design capacity, accompanied by effective fundraising, ensuring financial and administrative support; (3) Qualified staff: The park is managed by highly motivated and qualified staff; (4) Dialogue and involvement: Continuous communication with local actors, stakeholders, businesses, private organizations and citizens, with particular attention to the education sector; (5) Advisory role: The park is recognized as an expert partner and environmental advisor in local and regional networks; (6) Management and monitoring: Management and monitoring system linked to the Action Plan with various indicators.
- *-Weaknesses:* (1) Promotion: Weakness in promotion and marketing activities, lacking an assessment of future visitor markets; (2) Lodging Opportunities: Poor and limited lodging opportunities on the island, despite the presence of public real estate; (3) Coordination of actions: Sharing of actions among many actors, increasing the risk of failure due to coordination difficulties and conflicts.
- *Best practices*: (1) Governance: Strong commitment to governance, with the full involvement of local communities and their socioeconomic categories; (2) Institutional collaboration: Fertile institutional relationship with the municipalities of the Gulf of Asinara and other public bodies, facilitating the planning and approval of management plans; (3) Research on ecosystem services: Funded by the Ministry of the Environment, it made it possible to evaluate the biological capacities of ecosystems and habitats; (4) Skills and abilities: Growth in skills through participation in international networks, strengthening the ability to manage complex projects. Among the actions of the Charter that stand out for their originality and innovation, two initiatives stand out: *Asinara plastic free*, which combines active conservation, public awareness, stakeholder’s volunteer work, and the expertise of the Park's technical staff (“Spazzamare” boat); *Fish & Cheap*, which integrates conservation efforts and offers fishing-tourist clients an authentic fisherman experience while promoting lesser-known fish species.

4.2. ECST-related benefits and issues

The 66.7 % of participants stated to possess both Park and Protected Areas Network Quality Label and ECST certification. Regarding the tourist activity, the 66.7 % of the sample corresponded to tourism services (e.g., excursions), 26.7 % to guides, and 6.7 % to fishing tourism. Formal analyses were performed using SPSS-29 (Armonk, NY: IBM Corp). A one-sample t-test was run to assess the significance for each BE item (normative value = 3, benefit for values > 3; two-sided critical value p = .05). Overall, BE items were confirmed as significant, positive benefits (BE1: t = 6.57, p < .001; BE2: t = 7.78, p < .001; B3= 7.39, p < .001; BE4 = 13.00, p < .001; BE5 = 4.36, p < .001; BE6 = 3.80, p = .002; BE7 = 3.47, p = .004; BE8 = 3.80, p = .002; BE9 = 3.98, p = .002) (Figure 3). For the IS items, Cronbach's alpha confirmed the internal consistency of the scale (alpha = .83). The one-sample t-test was applied to the scale mean value (normative value = 18, benefit for values < 18; two-sided critical value p = .05), confirming that participants did not perceive issues related to the ECST (IS_TOTAL: t = -3.61, p = .003) (Figure 4).

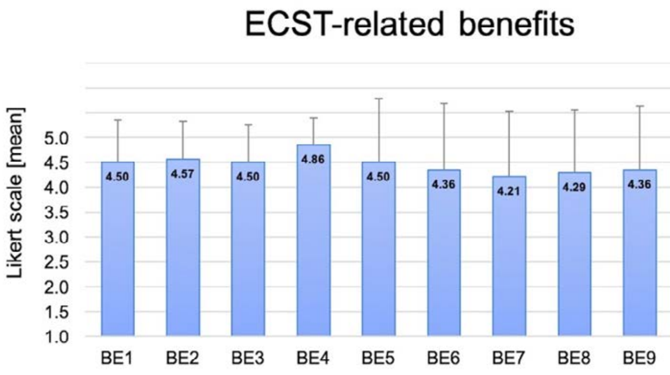

Figure 3 – Mean results of ECST-related benefits (i.e., BE items).
Notes. All p < .05. Error bars indicate standard deviations.

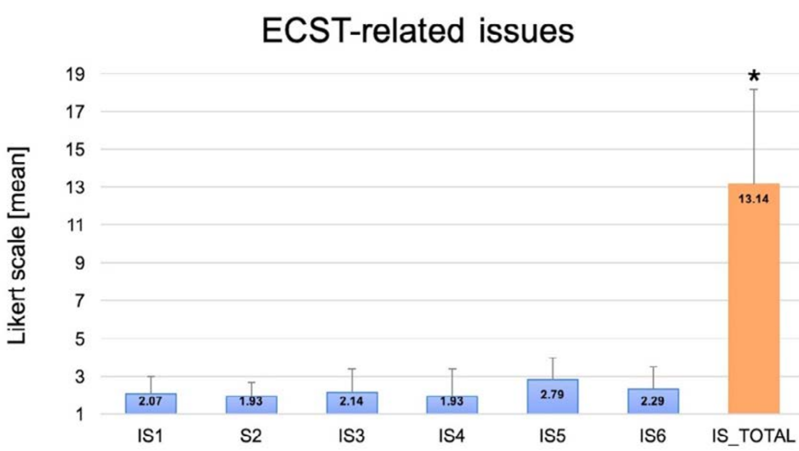

Figure 4 – Mean results of ECST-related issues (i.e., IS items). The total obtained for the scale (i.e., IS_TOTAL) is highlighted in orange.
Notes. * p < .05, indicated only for IS_TOTAL. Error bars indicate standard deviations.

5. Conclusions

Parks and other stakeholders identify the creation or strengthening of a territorial network as the main result of the ECST. The certification provides a general framework for developing specific projects and initiatives, facilitating access to funding through coordinated, long-term planning. The participation and dialogue established during the ECST process can form a solid basis for further activities in the area. The official external recognition of the participatory planning methodology and the membership of an Italian and European network of protected areas allow the comparison and carrying out of integrated promotion activities. Finally, the activities envisaged by the Charter's action plans are part of the Green Economy, offering businesses opportunities for growth and promotion thanks to the ECST brand and the alliance pact established with the protected area [14; 28; 32].

Overall, Asinara National Park has demonstrated significant strengths, including excellent planning capacity, considerable fundraising ability, and effective local community involvement, reflecting solid governance and sustainable resource management. The park still faces challenges in the field of tourism promotion and management of accommodation opportunities, which are currently insufficient. However, the best practices adopted and the constant commitment to governance and fruitful institutional collaboration constitute a successful model for the sustainable management of protected area. This successful model should reassure stakeholders about the future of the park, as it is well on its way to becoming an example of excellence in sustainable tourism, with further improvements needed in promotion strategies and coordination of shared actions. The results suggested a systemic vision of stakeholder involvement in creating a model for best practices to qualify the socio-economic network. Also, firms could recognize ECST certification as an affordable source of benefits. Thus, promoting participatory and inclusive governance could ensure a balance between sustainable tourism and environmental conservation in the delicate Mediterranean coastal landscape and on the island of Asinara.

The findings of this study have to be seen in light of some limitations. First, the small sample of participants in the questionnaire should be considered —mainly due to the overlap of the survey with the tourist season. Also, Asinara National Park's Phase I renewal operations application is ongoing.

Further research is crucial to update and expand the audience, not only to operators in possession of the Parks Network Quality Mark but to all companies within the Vast Area that have the requirements to access it. This emphasis on the need for further research should make stakeholders feel involved in the ongoing development of the ECST certification.

6. Acknowledgments

This study is part of a PhD research scholarship (PhD student: MGM) funded by the University of Sassari, Italy.

7. Authors' contribution

Conceptualization: VG, SM, DC; *Methodology*: MGM, SM, DC; *Investigation*: MGM, NP; *Visualization*: MGM (Materials), NP (Materials), SM (Results); *Formal analysis:* SM; Writing (original draft): MGM, NP; Writing-review and Editing: SM, DC; Supervision: VG, DC.

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FISHING TOURISM IN TUSCANY: CURRENT SITUATION AND FUTURE DEVELOPMENTS

Andrea Massaro, Marina Sartini, Francesco De Carlo, Ilaria Rossetti

Abstract: Professional fishery plays a crucial role in the development of the Tuscan economy. Currently, this sector involves more than 1500 people and 583 boats, producing around 11 000 tonnes/year of seafood products. Fishery in Tuscany is a multifaceted sector with solid cultural baseline that over the years has changed its own relationship with the sea. In the last decade, fishers and consumers have become aware of dangers that threaten the marine environment and in particular fish stocks. For this reason, fishers and their associations, assisted by fishery biologists, have decreased fishing effort and invested in other activities to integrate their income. Fishing tourism, for example, is a diversification of fishing activities and represents a sustainable activity for artisanal fishers, combining environmental protection, maritime culture, an alternative profitability and a connection between fisheries and tourism. There are currently 47 active fishing tourism licenses distributed along the entire Tuscany coast (including islands), mainly concentrated in ports of Livorno and Viareggio. These are mainly small-medium sized boats operating with passive gears followed by trawlers. From interviews carried out with fishers, fishing tourism is considered an important activity to reduce fishing effort without compromising income and to create new opportunities and networks.

Keywords: Fishing tourism, Small-scale fisheries, Tuscany

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Andrea Massaro, Marina Sartini, Francesco De Carlo, Ilaria Rossetti, *Fishing tourism in Tuscany: current situation and future developments*, pp. 440-447, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.40

In recent decades the professional fishery deals with some criticalities, the main of which is represented by the overexploitation of fish resources [4][5][17][19]. In addition, progressive degradation of marine ecosystems due to climate change, pollution and maritime activities in terms of maritime traffic have been observed [2][10]. Furthermore, pressures of tourism in coastal areas could negatively affect fishing activity, in particular artisanal fishery, removing the possibility for fishers to work in some areas during summer season [13]. This situation has repercussions on the fishers's economy.

Professional fishery plays a fundamental role in the development of the Tuscan economy. Currently this sector involves more than 1500 people and 583 boats, producing around 11 000 tonnes of fish products per year [1][24][5]. In this region, commercial fishery is a multifaceted sector with solid cultural roots and over the years has changed its relationship with the sea. In the last decade, fishers and consumers have become aware of dangers that threaten the marine environment and in particular fish stock [8][12][18][23].

In this context, requirement for fishers to protect fish resources by reducing catches and suggesting valid alternatives to supplement their income has become increasingly pressing [20]. Fishing tourism and ittio-tourism are activities capable of satisfying these aspects, combining environmental protection, fisheries culture and alternative profitability [3][6][11][21].

Since 1992, fishing tourism, is defined as an activity carried on by a single owner, or a company or fishers cooperative, aimed to transport people other than crew, such as tourists, for recreational activities (D.M. n. 293/99; D.M. 96/2006). Generally, a typical day of fishing tourism involves a trip where tourists can actively participate in fishing activities by learning fishing techniques; furthermore, they can eat freshly caught fish, as well as swimming and visit beaches that can only be reached by boat. Not all fishing vessels can conduct this activity. Vessels with licences for passive fishing gears (gillnets, trammel nets, longlines) are allowed while trawling can bring tourists fishing only with a rod.

Ittio-tourism is still a limited activity where tourists spend a day in the house of a fisher, renting a room and having traditional and local fish meals with his family [22]. This activity can only be practiced by professional fishers with a regular license.

This paper aims to provide useful information about the situation of fishing tourism in Tuscany; in particular a case study in Viareggio provided useful information and advice about this activity.

Materials and Methods

From April to August 2023, a survey was carried out regarding the number of fishing tourism licenses in Tuscany. The data coming from the EU Fleet Register, from the Agriculture and Rural Development office of the Tuscany Region, from the fishing cooperatives were analysed and verified through inspections at the main Tuscan harbours or on the telephone. The Coast Guard Fishing Department were also involved in the survey. Furthermore, a web search was carried out using specific keywords and excluding those activities that practice recreational fishing. Characteristics of the vessels (LOA, GT, kW, gears) and information about fishing tourism activity (time spent, maximum number of persons allowed on board, travel itineraries, rate, pros and cons) were recorded.

Results

From an administrative point of view, the Tuscan coast is divided into four maritime compartments (Marina di Carrara, Viareggio, Livorno and Portoferraio) where 26 fishing harbours can be identified. The Tuscan fishing fleet consists of 583 boats (CFR data, 08/2023) and is characterized by a high number of artisanal fishing vessels armed with passive gears (trammel net, gillnets and longlines). Trawling is widely represented throughout the region and contributes high levels of production both in terms of operators employed and catches (Fig.1).

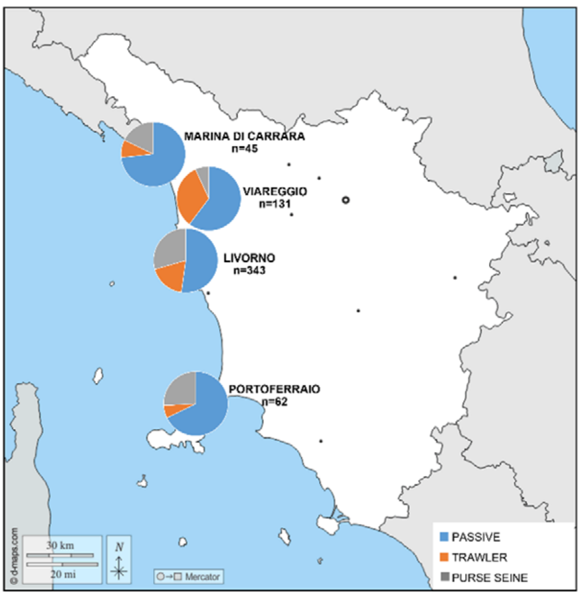

Figure 1 – Spatial distribution of the professional fishing fleet in the Tuscan maritime compartments.

At the time of the survey, 47 fishing tourism licenses were active in Tuscany. The authorized vessels are mainly distributed in the maritime compartment of Livorno (30 vessels) and Viareggio (8 vessels) (Tab. 1).

Regarding vessel registration harbour, the greatest number of licenses is found equally in the ports of Livorno and Viareggio (Tab. 2).

Vessels authorized for fishing tourism are mainly armed with passive gears (50.0 %) and purse seine (36.9 %). Vessels with a trawling license represent 13.1 % of the total (Tab. 3).

Table 1 – Number of fishing tourism licenses by maritime compartment.

Maritime Compartment	Number of Fishing Tourism Licenses
Livorno	30
Viareggio	8
Portoferraio	5
Marina di Carrara	4

Table 2 – Number of fishing tourism licenses by harbour.

Port	Number of Fishing Tourism Licenses
Capraia	3
Castiglioncello	5
Castiglione della Pescaia	1
Cecina	1
Follonica	2
Livorno	8
Marciana Marina	1
Marina di Carrara	4
Marina di Grosseto	1
Piombino	2
Porto Azzurro	2
Porto Ercole	2
Porto Santo Stefano	3
Portoferraio	2
Vada	2
Viareggio	8

Table 3 – Characterization of the fishing gear of vessels with a fishing tourism license.

Port	Passive	Trawler	Purse Seine
Capraia	3	-	-
Castiglioncello	2	-	3
Castiglione della Pescaia	1	-	-
Cecina	-	-	1
Follonica	2	-	-
Livorno	3	2	3
Marciana Marina	-	-	1
Marina di Carrara	3	1	-
Marina di Grosseto	1	-	-
Piombino	1	-	1
Porto Azzurro	1	-	1
Porto Ercole	1	-	1
Porto Santo Stefano	1	-	2
Portoferraio	-	-	2
Vada	1	-	1
Viareggio	4	3	1

Vessels with a fishing tourism license are small-medium sized vessels with limited engine power (Tab. 4). Analysing the data relating to vessels with a purse seine licence, we note that they have a second license for passive gears. Since these vessels have a length lower than 15.5 m LOA (Length Over All), it is plausible that the main gear is represented by passive gears.

Table 4 – Technical characteristics of vessels with a fishing tourism license.

Gear	LOA min (m)	LOA max (m)	Average Tonnage (GT)	Average Engine Power (kW)
Passive	6.5	14.1	5.8	78.2
Trawler	8.2	12	6.7	70.3
Purse Seine	7.1	15.3	6.1	72.4

Regarding ittio-tourism, in total 6 activities were found: 3 activities were found on the continental coast, 1 in Viareggio and 2 in the province of Grosseto and 3 on the islands of the Tuscan Archipelago, 2 on Elba Island and 1 on Capraia Island.

Viareggio case study

In Viareggio harbour, a total of 8 vessels were authorized for fishing tourism: 4 vessels belong to small scale fisheries, 3 trawlers and 1 purse seine. The latter has double fishery license (purse seine and gillnet): from a direct check, it has been confirmed that the vessel carries out its fishing activities mainly with gillnet. Table 5 shows the characteristics of vessels authorized to fishing tourism.

Table 5 – Technical characteristics of vessels in Viareggio with fishing tourism license (Gear: P=Passive; T=Trawler; PS=Purse Seine).

ID	Main Gear	Secondary Gear	LOA (m)	Tonnage (GT)	Engine Power (kW)	Hull
1	P	P	9.0	8.2	109.5	Fiberglass
2	T	P	11.1	9.8	58.8	Wood
3	T	PS	11.9	9.9	95.5	Fiberglass
4	T	P	11.6	3.4	84.5	Wood
5	P	P	11.1	9.8	132.4	Fiberglass
6	PS	P	11.6	9.7	148.0	Fiberglass
7	P	P	9.6	5.6	130.0	Fiberglass
8	P	P	14.1	9.3	216.0	Fiberglass

The results obtained from the interviews, highlighted that vessels authorized to fishing tourism are small-medium size vessels and carry out coastal fishing with gillnets/trammel nets or trawling with a 6 nautical miles license. Some vessels carry out longline fishing for white fish and swordfish.

Generally, 3 fishers carry out fishing tourism activities assiduously, 2 sporadically (less than 10 trips in a year) and 3 did not carry out trips in the last years. The maximum numbers of tourists allowed on board are 12 with an average of 10. There are no particular itineraries, but each fisher, according to weather conditions, decides where to carry out the activities. The duration of the activities varies from half a day to a maximum of 8 hours, and it does not include night experiences. The activity takes place mainly in the spring-summer months (from the end of May to the end of September) and price varies approximately between 60 to 100 euros per person depending on the duration of the activity.

Regarding ittio-tourism activities, in Viareggio a fishers's cooperative has opened in the local fish market a bar/restaurant promoting local fish, with particular attention on poor species (i.e. stingrays, mullets). The activity involves 8 workers and very often the fishers serve clients.

Discussion

In Tuscany, fishing tourism is well represented in many harbours, and it gives to fishers the opportunity to approach the world of tourist hospitality, representing an alternative source of income. In Italy, the activity is relatively new and in recent years the licenses issued have been increased [21]

The vessels have adapted to standards required by law, for example by adding bathroom and kitchen, or "ad hoc" vessels have been built so they can be able to continue the fishing activity, but at the same time to host tourists [21][22].

Fishing tourism belongs to the categories of "sustainable tourism" and "experiential tourism", helping to economically support local fishers' communities and, at the same time, sharing with tourists the cultural heritage of the world of fishing and his local traditions. [6][9][14][15][16] Furthermore, during the fishing tourism day, catches are limited to lunch needs. Therefore, fishers who carry out these income integrating activities are aware of the advantages for the environment in terms of reduced exploitation of resources.[6][8] In addition, crew takes advantage from these activities in terms of less physical and psychological strain.

Some critical issues emerged during the interviews. Trawlers that carry out fishing tourism are prevented by law from fishing with trawl net and the activity is limited to taking tourists fishing with rods. By applying the safety regulations also to the guests on board, the possibility of being able to use the trawl net, for example for just one haul a day, compared to the usual hauls of a normal fishing day, would be an added value for these boats and would allow the tourist to learn about a type of fishing often mistakenly considered "illegal" and harmful.

Furthermore, it clearly emerged that without a land-based structure capable of managing the organizational and logistical part, both fishing tourism and ittio-tourism are difficult to achieve. Generally, the organization (contacts with customers, advertising, logistics) is in charge of the fisher's families. There are few situations where there is no direct involvement of family members, but management is entrusted to the cooperative or external structures.

An aspect to be further developed should be communication between the world of fishing and the tourism sector [7][21]. This is fundamental to make these types of activities known to an ever-increasing number of users, who, as already mentioned, are interested in experiences different from normal tourist itineraries. In this context, it would be advisable for fishers to acquire technical, technological and marketing knowledge so they can be able to personally promote their fishing and fishing tourism activities and manage the bureaucratic aspects more easily. In this context, for example, the FishmedNet project (https://www.fishmednet.com/) was developed in order to create a Mediterranean-wide database on fishing tourism and ittio-tourism.

Conclusions

The results of this work show that fishing tourism and ittio-tourism have a great future, linking professional fishery and tourism. The benefits of the eco-tourism affect both environment and fishers' economy.

Fishing tourism proves to be a sustainable form of tourism, suitable for everyone, capable of raising awareness of a not well known and very often misunderstood sector. In addition, culinary tips and knowledge sharing by fishers about values of seafood constitute a plus for this experience.

On the part of the fishers, it is clear how the awareness of carrying out sustainable fishing is rooted, especially in the new generations, to preserve the environment by guaranteeing sustainable management of the resource. These represent the strong foundations of this activity. On the other side, bureaucratic support and a sponsorship network, should be created or strengthened, to allow the development of these activities.

Acknowledgements

Many great thanks for the help and collaboration to the people and associations involved in this research: Regione Toscana, Legacoop Toscana, Legacoop Agroalimentare, Cittadella della Pesca OP, Cooperativa Marenostrum, MP Evolution, MP MAS 500, MP Sofà and Portus staff.

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"LIGHTHOUSE FAMILIES" IN GREECE: THEIR CONTRIBUTION TO FORMING AND PRESERVING COASTAL CULTURAL IDENTITIES

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Abstract: The Hellenic Lighthouse Network (HLN) is one of the most historic and best organized coastal and open sea lighting systems across the world. Greek traditional built lighthouses and beacons are perceived as an integral part of coastal cultural identities since they encapsulate tangible and intangible qualities.

Lighthouse keepers in Greece have been influenced by the roughness of the landscape and the isolation of their profession. At the same time, their communities, the so-called "lighthouse families", have contributed to the construction and preservation of coastal natural and manmade cultural resources.

The paper seeks to delineate the cultural capital and tourism potential of life at lighthouses in Greece. It also underlines the significance of Greek lighthouse families' role in protecting, revitalizing and rebranding the cultural characteristics of coastal areas. The survey was conducted in the context of a doctoral thesis and was based on qualitative research methods. Literature review, study visits at lighthouse zones, and interviews with professionals in the field and persons emotionally connected with lighthouses, produced results that confirmed our research hypotheses.

Keywords: Hellenic Lighthouse Network, lighthouse keepers, lighthouse families, coastal cultural identity, Greece

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Introduction

The Hellenic Lighthouse Network (HLN) is one of the most historic, best organized and densest (about 1/10 km of coastline or 1/5.4 NM) coastal and open sea lighting systems worldwide. It includes more than 1600 lighthouses, beacons and buoys. Traditional built lighthouses and beacons were installed between 1822 and 1926, i.e., after the beginning of the Greek War of Independence against the Ottoman Empire (1821) and were gradually incorporated into the national marine and defence infrastructure. They have been characterized as Monuments of Modern Cultural Heritage since they were erected at least one hundred years ago [11].

The majority of Greek lighthouse complexes and buildings are found in locations of natural beauty and architectural interest; some of them are situated within conservation areas (e.g., Sapienza Island, Pylos) and world heritage sites (e.g., Fort of Old Town, Corfu). Greek lighthouses are almost handmade albeit remarkable and multifaceted structures that represent tangible and intangible qualities. They absorb local, national and global connotations, and reflect monumental, technological, political, social, practical, aesthetic and spiritual values. As a result, they are deemed to be a core element of coastal cultural identities to many regions and the whole country despite their practical utility being minimized due to their automation. Still, they enchant people pursuing sophisticated and reclusive activities beyond the mass tourism spectrum. Greek lighthouse scenery inspires authors and artists, too; that is why it is depicted in a plethora of literary works, music (lyrics and video clips), advertising and cinema products [9].

Lighthouse keepers are inextricably associated with the history, operation and protection of lighthouses. Each one's experiences, narratives, perceptions or emotions are unique. However, lighthouse keepers' collective 'habitus' [4], memory and expertise have comprised a sui generis cultural ecosystem. As a social group, lighthouse keepers in Greece have been influenced by the harshness of the Greek landscape and the extreme isolation of their profession. At the same time, their autonomous and self-dependent communities, the so-called "lighthouse families", have substantially contributed to the construction and preservation of coastal natural and manmade cultural resources over time. Notwithstanding, the modernization and digitization of shipping equipment and navigational aids, as well as improvement to access through sea routes and land roads, have simplified lighthouse keepers' routine. Their profession is considered obsolete, or even unnecessary, but their regular presence at lighthouses seems to be a catalyst for the sustainability of buildings, the surrounding environment, land and seascapes [9, 15].

The paper seeks to explain the cultural capital and tourism potential of life at lighthouses in Greece. It also discusses the importance of Greek lighthouse families' role in preserving, refreshing and rebranding the inherent cultural features of coastal areas. The survey was conducted in the context of a doctoral thesis and was based on qualitative research methodology [9]. Literature review, study visits at lighthouse zones, and interviews with people familiar with lighthouses, produced results that verified our hypotheses. Formal and unspoken rules of living and collaborating, intercultural communication, intergender and intergenerational relationships, kids' education, games and toys, food seeking, preparing and storing practices, ordinary, festive and mourning rituals, attitudes towards nature and spiritual matters, oral history and legends are some of the topics that were observed, reported and regarded as worth recording, evaluating, interpreting and disseminating under the scope of lighthouses forming and preserving distinct coastal identities in Greece.

Methods

The research was carried out between 2020 and 2023, in three stages. Relevant scientific books and articles were collected and reviewed; literary texts (novels, poems and song lyrics), films, advertisements and music video clips, posters, stamps and telephone cards were gathered and analyzed, too. Study visits and interviews were conducted throughout the research, most of them during its final phase.

The aim of the entire research was very broad and exceeds the limits of the present paper. Regarding lighthouse keepers, the aim was threefold: (i) focusing on particular aspects of their living and working conditions as a social group, with emphasis on the 19th and 20th centuries (i.e., before the automation of lighthouses), (ii) explaining the non-obvious or underestimated importance of lighthouse families for the integrity and evolution of coastal cultural identities, and (iii) suggesting ways of recognizing, preserving and promoting that exceptional cultural ecosystem through tourism and educational activities.

Scientific research on lighthouses has been developing mainly after their automation and/or decommissioning (late 20th century). The growing number of such publications could be attributed to the fact that lighthouse complexes and surrounding areas are in danger of alteration and/or loss of their tangible and intangible characteristics, since lighthouse keepers have gradually evacuated them. Although environmental and climate pressure has been a permanent threat to lighthouses, due to their marginal locations, human presence has always worked protectively, both preventively and restoratively. Many of the relevant works come from the field of applied science and usually refer to the maintenance, reconstruction and utilization of specific buildings [10, 18] or suggest lighthouse architectural standards for strengthening coastal communities' resilience against climate change [17]. Social sciences and humanities are mostly interested in lighthouse keeping as a working and living milieu, bizarre or historical incidents and notable personalities (engineers, keepers, etc.) [1, 3, 8, 16], the postmodern use of lighthouses for cultural and tourism purposes [2, 12, 13, 14] or critical approaches to well-known literary texts and films referring to lighthouses [5, 6, 19].

Searching for 'lighthouse texts', i.e., literature, films, songs, etc. that mention or implicate lighthouses as buildings, locations or symbols, was based on criteria (keywords), such as 'lighthouse', 'beacon', 'lighthouse keeper' and 'lighthouse keeping', in Greek and English language. While research being in progress, it was found that vibrant lighthouse allegory also appears on book or disc covers and film promotion posters regardless of their literal content. As a result, hundreds of similar 'items' were found but only some of them were accessible through libraries, bookstores, archives, etc. In total, ninety novels, short story and poem collections, forty-two films, two hundred and fifty songs and dozens of other 'lighthouse' objects were analyzed (context analysis method).

Study visits were considered as a necessity for a research of this kind. It was a hands-on, context-based, embodied approach to experiencing, recording and understanding authentic conditions at lighthouses although a lot of things have become easier nowadays compared to the past. The selection of the fifty-four lighthouses (1/3 of protected ones) that were studied was based on their accessibility, approval from the Lighthouse Service and/or communication with competent lighthouse keepers (if any), the strategic/geopolitical perspective (regions of Hellenic Maritime Space), geographical (mainland and islands), micro-local (degree of difficulty in access), historical (period of construction) and morphological (type of construction and current state) importance of the buildings. During visits, a series of characteristics were taken into account according to IALA recommendations on the preservation of lighthouse heritage [7]. An observation grid including a series of closed (Yes/No, gap filling, grading, etc.) and open-ended (lighthouse keeper presence, exact location, situation, marked trails, other close-by places worth visiting, etc.) questions was used to estimate each lighthouse's cultural meaning and tourism potential.

The interviewees have supported and showcased Greek lighthouses with their work or have been connected to lighthouses through their family biography. They are lighthouse keepers, lighthouse keepers' adult relatives, Lighthouse Service officers, and professionals who have included references to lighthouses in their work. Interviews were given by ten active and five retired lighthouse keepers, eight relatives (offspring, grandchildren, godchildren, nieces-nephews), three (civilian and military) Lighthouse Service officers, four writers, a photographer, a painter, an architect and a former Lighthouse Service Commander and author of books dedicated to the history of the HLN. A list of questions was created to ask all of them; some of the topics discussed were lighthouse symbolism, cultural and tourism use of lighthouses, lighthouse keepers' education and role, etc. Interviews were semi-structured, so that participants could feel free to talk about the duration and quality of their relation to lighthouses or any thoughts regarding the survey.

Results

Our research process has generated multiple findings confirming the hypotheses regarding lighthouse families in Greece: (i) Greek lighthouse families' living and working conditions constitute a versatile cultural ecosystem, (ii) Greek lighthouse families' contribution to the integrity and evolution of coastal cultural identities has received little scholarly and institutional (governmental) attention; thus, it is neglected or even disdained, and (iii) that unrivalled cultural capital could be studied, classified, interpreted and signposted through tourism and educational activities ensuring sustainability for lighthouses and coastal areas as cultural entities. The results can be organized in three sections, as follows:

(i) Aspects of Greek lighthouse families as a social group: People who worked and lived in lighthouses in the past two centuries composed an unconventional social group. Lighthouse attendants, assistants and technicians, as well as members of their families and rare guests (inspectors, doctors, castaways or passers-by), coexisted, permanently or occasionally, under the same roof. They had to collaborate harmonically and perform demanding standardized tasks round-the-clock in order to keep lighthouses neat and functional. Prescribed rules and ethical principles regulated relations in lighthouses but also between their inhabitants and the external world: the authorities, seafarers and local communities. Whoever violated the canon was punished or suspended. Modus vivendi and operandi was not as idyllic as described in romantic or thrilling pieces of literature and art. In fact, hard work and limited space or other resources in Greek lighthouses, most times away from civilization, could change the dynamics any time, but lighthouse families had to find a new balance quickly and remain attached to their common goal. Cohabitation was experienced differently by each person, depending on a number of factors, such as reasons for being there, duration of a shift or appointment, distance from mainland or populated areas, age, etc.

Lighthouse families developed codes of communication with people from other cultures that needed their guidance or care. They had to be supportive, undiscriminating and tolerant within their communities, too; women, children and elderly parents usually lived with lightkeepers and assisted them with chores because they could not afford an extra home. Tenure at lighthouses turned into a family affair. Approval from the Lighthouse Service was required in order for lighthouse keepers to enter into marriage; their wives had to be Greek and were checked for any subversive opinions until the 1970s. Traditional gender roles were the norm except for cases that women or young members of the family had to be in charge, when lighthouse keepers were ill or injured. Between 1920 and 1935, the Greek State hired about fifty destitute lighthouse keepers' widows on short-term contracts, because of transfers or leaves that Balkan Wars and World War I had induced.

Children had to adapt to those conditions and parental work mobility, learn from nature, siblings and adults, or sometimes be prepared to follow an almost predestinated career in lighthouse keeping. As for their routines, lighthouse children were very imaginative. Apart from helping with lighthouse operation or going to school (if there was one at a reasonable distance), children were educated at home, learned to be responsible for younger siblings and pets, invented games outdoors and crafted toys from materials found everywhere, loved swimming, diving and fishing, enjoyed reading and storytelling, respected the elderly and appreciated life. Lighthouse children often came face-to-face with sickness and death; they perceived them as a natural part of the life cycle. Some of the retired lightkeepers in our research confessed to having been importunate with juveniles; on the contrary, participants that had lived at lighthouses when they were kids said that the whole experience was only for the benefit of their personality and skill building. It is worth noting that lighthouse keepers' daughters and sons participating in our research recalled life at lighthouses with nostalgia.

According to some interviewees, lighthouse families' attitudes towards nature were 'rather healthy'. Austerity and nativeness of materials and techniques in Greek lighthouses construction have rendered them eco-friendly and compatible with their natural surroundings anyway; they seem to cause no rupture or intrusion into land or seascapes. Lighthouse keepers served in places exposed to wild natural phenomena, trying to early warn about severe weather changes, prevent accidents and protect crews, passengers, freight and the environment from disasters. They had no intention of taming nature; instead, they admired its genuine sublimity and power, and expressed their feelings in stories, poems, paintings and handicrafts in their leisure time. Spiritual concerns differed among lighthouse residents, depending on each one's personal life route and mindset. Generally speaking, most members of lighthouse families believed in God and kept Orthodox Christian tradition alive through their everyday, festive and mourning customs. Religious and patriotic books provided by the Lighthouse Service cultivated devotion to God and the State.

Food and water procuring and storing was a logistical enigma for lighthouse families. Scheduled visits from supply ships were not frequent and long distances were difficult to travel even by boats or donkeys provided by the Lighthouse Service. Lighthouse families had to manage their supplies prudently and improvise alternative solutions, such as growing small farms with vegetables, herbs and domestic animals (hens, goats, etc.), going fishing or hunting, and preserving goods. The ground was not always tender but survival instinct, creativity and cooperation brought results. Lighthouse families faced the same problems with materials and parts for the maintenance of lighthouses, as well as for their own medical care. Conditions at lighthouses and scarcity of professional medical treatment resulted in some members of lighthouse families sickening, dying and being buried near lighthouses.

Historical sources about Greek lighthouses are rare or incongruous; oral history and lighthouse logs fill the gaps. Until the beginning of the 20th century, education was not compulsory in Greece and illiteracy rates were higher in remote areas. Lighthouse zones were no exception to that rule. Lighthouse families struggled to serve their sacred duty and survive; storytelling was an educative, comforting and uniting habit, a way of bringing people together, as well as a means of preserving the meaning of lighthouse keeping as a vocation. Isolation and, sometimes, substance use produced stories teeming with heroic deeds, fairies, mermaids and ghosts. Writers participating in our survey admitted being inspired by such stories, while other interviewees remarked that literature and cinema have exaggerated or idealized life at lighthouses.

(ii) The importance of Greek lighthouse families for the integrity and evolution of coastal cultural identities: All methods implemented in our research showed that Greek lighthouse families' legacy has received little attention although legislation protects lighthouses as modern monuments. Scholars and governmental or regional bodies in Greece study and promote lighthouses sporadically through publications or small-scale cultural activities, respectively. Nonetheless, lighthouse families' intertemporal role in forming and preserving coastal cultural physiognomy is either underestimated or even ignored. Greece developed its territory, diplomacy and trade, spread its civilization and evolved as a maritime nation via the sea highways. Lighthouses have become recognizable and treasured landmarks, while their curators have contributed to the establishment of Greece's long nautical tradition; therefore, they deserve more scientific concern and targeted publicity by competent stakeholders.

Lighthouse families' cultural significance is not defined or visible either in academia or in tourism development plans for several reasons listed in the research. Just to name a few of them, the philosophy of the Lighthouse Service is military, lighthouses are still part of the national defence system, economic and legal restrictions hold maintenance and valorization initiatives or private sector engagement back. As a result, a magnificent cultural universe is at risk of disappearing into oblivion, whilst meticulous documentation, evaluation, interpretation and prominence of lighthouse families' organization, practical knowledge, gastronomy, customs or legends could anticipate deterioration or irreversible damage to coastal identities, offer sustainable approaches to contemporary challenges related to climate crisis (e.g., sea level rise, erosion, drought, biodiversity loss) and invigorate national cultural product with broader effects on Greek economy and society.

(iii) Ways of recognizing, preserving and promoting Greek lighthouse keepers' legacy through tourism and educational activities: According to our research findings, acknowledging lighthouse families' heritage as a distinct and influential component of coastal cultural identities could be the first step to systematically preserving and promoting it. One active lighthouse keeper, his father's successor to lighthouse posts, said characteristically: *'What happened at lighthouses some decades ago should not stay there; it is time scholars and authorities dealt with life at lighthouses seriously. Authors and painters have done a good job but the real thing is still undisclosed. Our generation* [lightkeepers today] *has a critical role, too'*. Additionally, a retired keeper compared lighthouse heritage to that of ancient monuments and expressed his expectation that soon politicians, experts and citizens would be as aware and proud of lighthouse cultural capital as he was.

What those two interviewees implied was actually repeated in some more interviews. If lighthouse heritage is going to be protected and showcased so that it continues determining the cultural character of Greek coasts, effective measures must be taken immediately. Environmental pressure is accelerating sea and landscape transformation; a horizontal, comprehensive and feasible strategic plan ought to be put into action urgently. The majority of research participants emphasized the Lighthouse Service policy and funding. They remarked that increased extroversion could make lighthouses more attractive and accessible to experts from many disciplines and the general public, but budget is considered a crucial parameter, too. A low-cost entrance fee and private sponsorship were suggested as legitimate sources of extra revenue for the Lighthouse Service to be able to expedite and intensify their diligent efforts to keep lighthouses alive.

Modern lighthouse keepers in Greece have a pivotal role in preserving and interpreting the heritage of their profession provided that they are trained to develop 'postmodern' knowledge and skills. History, geography, geology and tourism management subjects should enrich their training curricula and everyday practice so that they can host and guide visitors or work as 'multipliers' in educational projects addressed to teachers, students or other interested groups. Around sixty lightkeepers take care of the HLN nowadays; traditional built lighthouses are more than one hundred and forty. Numbers speak of a disproportion that cannot ensure the sustainability of lighthouse buildings and surrounding areas. Dissemination of lighthouse legacy into primary and secondary school, vocational training and university syllabi, as well as tourism event planning, would probably amplify its visibility and guarantee its protection for present and future generations. More knowledgeable lighthouse keepers, with a positive attitude towards the necessity and usefulness of their new job description, would best respond to such a quasi-existential challenge.

In any case, study visits and participants' statements concerning limited carrying capacity (small gross internal and external area), combined with rough topography of Greek lighthouses, pointed to similar conclusions: only small-scale events could take place inside or in the courtyard of particular complexes, e.g., lighthouse training classes, art exhibitions, literature tributes, weather or wildlife observation boot camps, treasure hunting. Lighthouses in Greece are too delicate and/or inaccessible to welcome great numbers of visitors simultaneously. Digital technologies (e.g., virtual and augmented reality, artificial intelligence) could increase public outreach and alleviate or support lightkeepers' duties, through information archiving and parameterization, identification of lighthouse cultural features, reviving life at lighthouses, monitoring conditions at buildings and neighboring locations, trail designing and maintenance, museum or educational interactive activities preparation, etc. Lighthouse families' heritage should have a central position in any endeavor of this kind.

Discussion

Lighthouse families have been the 'soul' of lighthouses, coastal and backcountry areas, and maritime history in Greece. They have worked diligently, in low-paid and high-responsibility jobs, putting on the map and bolstering communities forgotten by governments, and protecting land and sea ecosystems. Their existence has been full of contradictions: independence and military obedience, freedom and imprisonment, stability and volatility, isolation and communication, alienation and cohesion, cosmopolitanism and provincialism, progressivism and conservatism are intermixed in their world. These antitheses have rendered lighthouse cultural wealth so attractive and lighthouse families' contribution to cultural identities so unique.

Small provincial societies respected lighthouse families; lighthouse keepers were honored like doctors, teachers and priests. They acted as liaisons between local communities and the central administration, while lighthouses functioned as meeting points, information hubs, or even decision-making centers. Besides, needs at lighthouses in terms of materials, tools and labor, as well as lighthouse keepers' humble but stable salaries, boosted local economies.

One could argue that the same ethos can be observed in lighthouses or other remote places everywhere on Earth. A comparative analysis of national lighthouse systems could reveal a lot of similarities. Indeed, literature review has shown that lighthouse families in other countries have more or less performed their duties; their cultural capital has been recognized and preserved thanks to central policies and/or local initiatives, mainly in the so-called 'Western' world. In contrast to lighthouses in other countries, Greek lighthouse structures are gradually abandoned and desolated after their automation, despite being protected as modern monuments. The number of lighthouse keepers and technicians reduces due to retirements and scarce new placements, budgets are tight, private involvement is discouraged or hindered; as a result, lighthouse cultural adding value, tangible or intangible, is in jeopardy.

Greek lighthouses epitomize the turbulent historical transitions of Modern Greece; so do lighthouse families. While Greece was trying to catch up with other European countries, lighthouse families had to overcome a myriad of adversities and created their own cultural 'hallmark': the emergence and maturation of the Greek State after nearly four centuries under Ottoman rule, World and civil wars, dictatorships, pirates, smugglers and traffickers, illiteracy, bureaucratic rigidness and nepotism, economic crises and cutbacks, and, lately, climate change. Nevertheless, lighthouse families have managed to keep their lighthouses illuminating the horizon and become an integral and solid part of Greek culture, a peculiarity of which has been family-orientation, i.e., close bonds among family members.

Although lighthouse equipment has always been advanced, following international standards thanks to Stylianos Lykoudis' persevering efforts (Army Navy Officer, Head of Lighthouse Service, first half of 20th century) and pressure from shipping companies and political players, life at lighthouses has had its own rhythm and originality. Lighthouse families have embraced innovations, preserved their traditions, responded to challenges, survived and created a whole cultural habitat with impact on neighboring areas.

Modernity was 'implanted' in lighthouses by female presence, too. Although women's recruitment was a matter of force majeure, temporary and/or of welfare nature, it was groundbreaking for Greece of the early 20th century, since it signaled their entry: a) in a male-dominated, 'masculine' working space, b) in a military profession, to which they could have access only as nurses until then, and c) in paid jobs in the public sector, where their employment was still an exception. Women's position at lighthouses was deemed as an extension of their traditional and socially acceptable duties as housewives. It was not perceived as provocative or anti-conformist, so it did not cause any reactions. On the contrary, it softly opened the way for other women to question culturally constructed dividing lines and gain visibility in the public sphere.

Greek lighthouse families' cultural contribution is inestimable. Its uniqueness deserves documentation, respect and strategic incorporation in national cultural and tourism policy, especially in the modern era of globalization and cultural homogenization.

Conclusion

Lighthouses have been guiding seafarers, and decorating coasts and dangerous outcrops since the distant era of the archetypical Pharos of Alexandria. They have prevented shipwrecks that would have adversely affected people, cargos and the environment. Lighthouses radiate light, hope and safety, but they would seem just spiritless material constructs if lighthouse families did not inhabit, operate and preserve them.

Lighthouse keeping has been more than a marine profession in Greece; it represents an idiosyncratic and multifaceted cultural ecosystem that has been influencing coastal identities in ways explained in this paper. Although their job description is different than it was in the past two centuries, lightkeepers are still responsible for the sustainability of buildings and surrounding areas. Their role is even more solitary nowadays, since their families do not follow and support them with lighthouse tasks. However, lighthouse keeping can be modernized without losing its military character. It can be enriched to include new knowledge and skills that could render lighthkeepers suitable for interpreting, revitalizing and rebranding the cultural characteristics of both lighthouses and coastal areas in the context of small-scale tourism and educational programs.

Most of Greek lighthouses are too delicate or unapproachable to host great numbers of visitors; still, some of them, that could be selected upon certain criteria (e.g., location, current situation, carrying capacity, lightkeeper presence) can operate as cultural and tourism hubs that will revive life at lighthouses through targeted events, such as guided tours, book reading evenings, wild life observation camps or other activities suggested in our study, with emphasis on lighthouse families' heritage, and could rejuvenate and diversify the national tourism product.

Acknowledgments

The registration fees were totally covered by the University of West Attica/Interinstitutional Program/Business Operation Management

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SUSTAINABLE DEVELOPMENT IN VULNERABLE COASTAL ZONES: THE CASE OF ABRUZZO

Cristina Montaldi, Gianni Di Pietro, Chiara Cattani, Francesco Zullo

Abstract: Coastal areas are pivotal in socio-economic and environmental contexts. They face heightened vulnerability due to their strategic significance and high population density, particularly evident in countries like Italy. The study areas are the 19 Abruzzo Region coastal municipalities, with a specific focus on the coastal belt of 1km. The main objective is to examine urban transformations and their causes driven by economic and demographic factors. For a strategic perspective on future territorial transformations the Planning Tool Mosaic (PTM) has been used. Municipal plans in Italy often overlook neighboring municipalities, resulting in disjointed management policies linked only by administrative borders. This study aims to provide a deep understanding of urban dynamics, identifying areas of high environmental value and assessing the economic and demographic energy of each municipality. By evaluating these aspects holistically, the study seeks to justify and adjust planning provisions to ensure sustainability, mitigating the loss of ecosystem services like crop production, water storage, and carbon sequestration. This comprehensive approach is crucial for fostering sustainable development in vulnerable coastal territories.

Keywords: Human and natural landscape, sustainability of coastal ecosystems, urban planning.

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Cristina Montaldi, Gianni Di Pietro, Chiara Cattani, Francesco Zullo, *Sustainable development in vulnerable Coastal zones: The Case of Abruzzo*, pp. 459-472, DOI: 10.36253/979-12-215-0556-6.42

Introduction

Coastal areas are extremely active in terms of urban transformations but at the same time they are extremely complex and fragile systems. These areas have a high level of environmental value [11] but they are subjected to strong anthropogenic pressures linked specifically to the high population density. Many scientific studies investigated the high fragility of the Mediterranean regions that are characterized by intense phenomena of land consumption [18]. Land use changes have impact on different ecosystem services. For example, they determine the variation in the surface water infiltration capacity [21,12], in soil carbon capture and storage [19] and in agricultural production [24].

In this paper, these three ecosystem services have been analyzed in reference to different scenarios. Specifically, two crono-section have been considered (2012 and 2021) for the measured variation in land use and forecast scenarios for future land use have been elaborated. For the last scenarios the Planning Tool Mosaic of the considered municipalities have been used (Figure 1c). Starting from the current settlement configuration, the work shows both what the future urban layout could be since the forecasts of urban plans and their possible effects on the above-mentioned ecosystem services.

The study area (Figure 1b) are the 19 Abruzzo Region coastal municipalities, with a specific focus on the coastal belt of 1km. The choice of this area is linked to the fact that this stretch is the one most affected by urban phenomena related to the economies of the sea, as also demonstrated by recent studies [3]. The importance of these areas for the regional demographic and economics dynamics becomes clear investigating what happened in the last 10 years. Between 2013 and 2023 the population of the Abruzzo region is decreased of about 40 000 people, instead of the coastal municipalities that increased their population of about 9 000 people. 14 municipalities of the 19 studied have a population higher than 10 000 people with 3 of them that surpassed the 40 000 inhabitants (Vasto, Montesilvano and Pescara).

The study area extends for 640 km^2 with a population of about 440 000 people for 2023. The population density (DA) of the area is 683 inhab./km^2, with the highest value for the municipality of Pescara (3479 inhab. /km^2). Values like that are very high if compared to the national (about 200 inhab. /km^2) and to the regional one (about 120 inhab. /km^2). Morphologically, the 130 km of Abruzzo coastline are rather uniform, with flat formations, low and sandy beaches and a flat or low hilly hinterland. This morphology has facilitated both the construction of infrastructures and productive-residential settlements. The presence of important infrastructure like highways and high-speed rail has allowed the growth and strengthening of urban centers. Coastal Abruzzo's settlement can be considered linear urban sprawl, growth mainly during the 60's and 70's.

From an economic point of view, coastal municipalities contribute more than a third of the regional taxable income (reference year 2021). Despite the strong anthropization, it is still possible to identify areas that preserve important natural traits, which, however, with less than a couple Special Areas of Conservation are subject to forms of protection that allow margins of transformability (e.g. Landscape Plan).

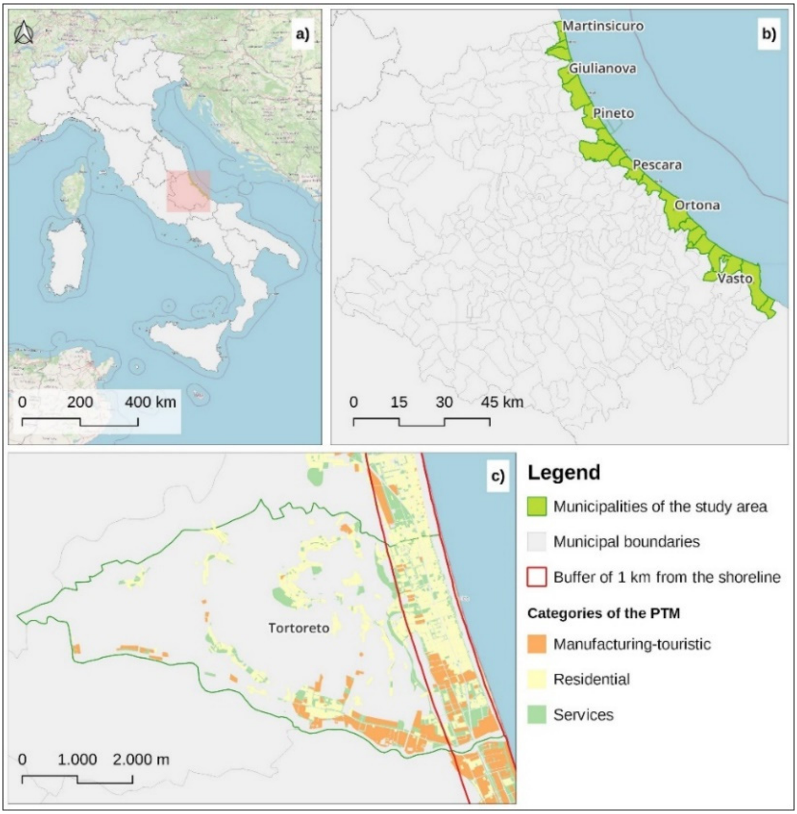

Figure 1 – Study area. a) position of the Abruzzo region in Italy, b) municipalities of the study area, c) example of PTM (Planning Tool Mosaic) for the municipality of Tortoreto, with the buffer of 1 km from the shoreline.

Materials and Methods

The elaborations contained in this work required the use of data of different nature from multiple sources. The reconstruction of the geography of the future urban settlement was carried out by reconstructing the framework of municipal urban planning instruments (PTM). The techniques for the construction of this tool are consolidated and used in several articles of the scientific literature [4,9,13,15,20,25,27]. The PTM required the retrieval of plans at the institutional portals of the individual municipalities, a pre-elaboration (georeferencing, digitization, elaboration of the union framework) and the reclassification according to the homogeneous territorial zones defined by Ministerial Decree 2 April 1968, No. 1444. This process involves a certain discretion in the zonal attribution; however, this is a reversible process because the original description of the area is always preserved in the database. The territorial zones are thus defined as:

A parts of the territory concerned by urban agglomerations that have a historical, artistic character and of particular environmental value or portions of them, including surrounding areas, which may be considered to be an integral part, for those characteristics, of the agglomerations themselves;

B parts of the territory that have been totally or partially built up, other than (A) zones: partially built up are those areas in which the covered area of existing buildings is not less than 12,5 % of the buildable area and in which the territorial density exceeds 1,5 m^3/m^2;

C parts of the territory intended for new settlement complexes, which are unbuilt or in which the pre-existing building does not reach the limits of surface area and density referred to in point (B);

D parts of the territory intended for new settlements for industrial installations or similar;

E parts of the territory intended for equipment and installation of general interest, public spaces, or spaces reserved for collective activities, public green, or parking, with the exclusion of spaces intended for road locations.

In this specific case, it has been decided to further simplify and the above zones. They have been reduced to three categories (Table 1) to make the reading of the phenomena more immediate.

Table 1 – Reorganization into categories of the zoning by D.M. 1444/68.

Category	Zoning (D.M. 1444/68)
Residential	B, C
Manufacturing-touristic	D
Services	F, S

The analysis for carbon sequestration was conducted through the open-source software InVEST (Integrated Assessment of Ecosystem Services and Tradeoffs) version: "InVEST 3.12.0 Workbench", which is a suite of models, including that of Carbon Storage and Sequestration (CSS). The methodologies used for the evaluation of models follow the flowchart already tested in other geographical areas [4,28]. The *Istituto Superiore per la Protezione e la Ricerca Ambientale* (ISPRA) data on land use were used for the assessment of these ecosystem services. The data used can be found at the following link https://www.isprambiente.gov.it/it/banche-dati/banche-datifolder/suolo-e-territorio/uso-del-suolo (accessed on 10 April 2024). Two years were considered: 2012 and 2021. The most up-to-date data for 2022 was not used as it is affected by errors for the study area. The geometric resolution of the data is 10 m/pixel. This data has different categories of land uses identified with a unique code, the corresponding with the description is shown in Table 2.

Table 2 – Legend of ISPRA land uses for the study area.

CODE	Description
2	Forest use
3	Quarries and mines
4	Urban and similar areas
5	Water uses
11	Arable crops
12	Forage
13	Permanent crops
14	Agro-forestry areas
16	Other agricultural uses
61	Wetland areas
62	Other non-economic uses

The model (based on the IPCC guidelines [7]) requires four types of carbon pools:

- epigeal biomass (C above), which includes all living plant material above the soil (e.g., bark, trunks, branches, leaves);
- the hypogean biomass (C below), comprising the living root systems of the epigeal biomass;
- soil organic matter (C soil), which constitutes the largest terrestrial carbon pool;
- dead organic matter (C dead), which includes litter and dead wood (both ground and dead logs still standing).

These input data were derived from the SimulSoil database using the different sources [5,6] and adjusting the legend to the one in the ISPRA land cover data as reported in Table 3.

Table 3 – Values of the Carbon Pools for model Carbon Storage and Sequestration for land uses.

Land use code	C above	C below	C soil	C dead
2	40,67	21,63	77,77	14,02
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
11	5	0	97,01	0
12	0	0	142,47	0
13	10	0	92,8	0
14	10	0	44,8	0
16	0	0	93,79	0
61	0	0	0	0
62	0	0	0	0

The economic value of the seized carbon (expressed in EUR/ton) was derived from Trading Economics (carbon price from the ETS (Emission Trading Systems) market on 29 April 2024 https://tradingeconomics.com/commodity/carbon.

As regard the crop production and water storage InVEST has not been used for the lack of input data. For this reason, evaluations about crop production follow a methodology already tested [26]. Soils considered as agricultural are identified by the code 11,12,13 and 16 reported in Table 2. Values for agricultural yield come from the Abruzzo region website (reference year 2014) [16] and price value comes from *Istituto di Servizi per il Mercato Agricolo Alimentar*e (ISMEA) [10]. Yield values are expressed in 100 kg per hectare, prices in euros per 100 kg.

The land use legend does not provide information about the type of cultivation present on the ground, for this reason in this study has been considered the wheat as cultivation. The values of crop production are available by provinces, so for this study the mean value of three involved provinces has been considered. This value is equal to 6000 kg per hectares. The conducted analysis on crop is a purely economic estimate and does not correspond to the biophysical value of the service of agricultural production however conditioned by the uncertainty of yield and average price that have been considered. The economic assessment is provided as a support, to understand the size of the environmental impact expected from the implementation of the transformation forecasts of municipal urban plans [2].

The last considered ecosystem service is related to water storage. Specifically, it was estimated the variation of runoff linked to the land use variation. Reference was made to the rational method which is a method to evaluate the flow of water through a specific section of a basin [22]. This empirical method, based on Equation (1), has different conditions to be met for its correct application, especially relating to the calculation of the intensity of rain. However, this study is outside the scope of the water discharge calculation but focuses on the evaluation of the runoff coefficients.

$$Q = \varphi \, i \, A \quad (1)$$

where:
Q = water discarge [m^3/s];
i = rain average intensity [m/s];
A = catchment area [m^2];
φ = runoff coefficient [-]

In this case, it was considered that, with the same intensity of precipitation (i) and area of basin (A), the parameter which varies, depending on the change in land use, is the runoff coefficient φ. The water discharge infiltrated varies proportionally to the degree of waterproofing and, for this reason depending on the variation of the ground cover. For example, soil with 50% of sealing determines a runoff rate five times higher if compared to natural soil. The runoff coefficient φ (variable from 0 for fully permeable surfaces, to 1 for impermeable surfaces) is the parameter that determines the transformation of rainfall-runoff. This coefficient is equal to the ratio between the volume flown through an assigned section and the meteoric volume. In this study, the evaluation of φ values was made considering the permeability characteristics of the draining basin cover and it comes from scientific literature [8]. The used values are reported in Table 4. As a precaution, the runoff coefficients are considered constant throughout the weather event.

Table 4 – Values of the Runoff Coefficient.

Code	Description	φ
2	Forest use	0,2
3	Quarries and mines	1
4	Urban and similar areas	0,74
5	Water uses	0
11	Arable crops	0,7
12	Forage	0,4
13	Permanent crops	0,6
14	Agro-forestry areas	0,6
16	Other agricultural uses	0,6
61	Wetland areas	0
62	Other non-economic uses	0,7

Results

The carbon capture and storage examination has been done using InVEST model. Specifically, the analysis regard all the municipalities of the Abruzzo coast with a deepening for the area of 1km from the shoreline. From the output data of the model, it is possible to define perspective scenarios both whole study area and for each municipality. Particularly, the first result regards the land use change registered between 2012 and 2021. It results that in the study area natural land are decreased for an amount of 177 hectares for the increase of urban land. The municipality with the highest change is San Salvo that loss about 27 hectares of natural areas. For this changes in land use there is a change in carbon capture and storage capacity of the soil. Specifically, in this period, the study area loss about 13 000 tonnes of carbon (tC) about 1480 tC per year. The municipality with the highest loss is Roseto degli Abruzzi (-2710 tC). There are also 4 municipalities (Ortona, Francavilla al Mare, Martinsicuro and San Vito Chietino) that register a total increase in carbon storage capacity of 3000 tC. These variations correspond to a total economic loss of about 900 000 €, the value for each municipality is reported in Figure 2 by the dark green bars. It results that the highest loss is the one of Roseto degli Abruzzi equal to 180 000 € (about 20 000 €/y). On the other hand, Ortona earns about 8300 €/y due to the increase in natural land use soil.

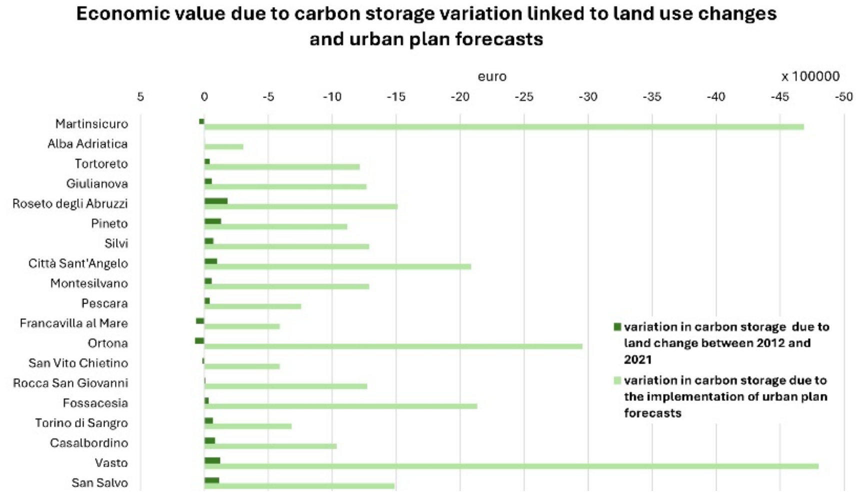

Figure 2 – Economic value due to carbon storage variation linked to land use changes and urban plans forecasts. The data are reported for each municipality ordered from the north to the south.

It is interesting to compare these findings to the one from the implementation of the urban plans. In general, the plans forecast for the study area attribute 43 % of the plan forecasts to the residential sector, 31 % to the manufacturing-touristic sector and 21 % to the services. The future implementation of these forecasts inevitably caused a reduction in soil carbon storage, specifically the following results represent what will happened with the total implementation of these forecasts. It results that the municipality that could loss the highest capacity in carbon storage is the one of Vasto (- 71 000 tC). InVEST model has also the output for the economic value linked to soil variation, as shown in Figure 2, since in all municipalities the carbon storage decreases with the implementation of the plans, the economic value is negative. Specifically, the municipalities of Martinsicuro and Vasto recorded the highest lost (higher than 4,5 million euro per year since the total implementation of the urban plans). The interesting things is that the economic loss due to the full implementation of all the urban forecasts is 34 times higher than the one recorded for land use changes registered between 2012 and 2021.

As declared in the introduction the study is also referred about the first kilometer from the shoreline. Specifically, it is interesting to understand the weight of this area in the variation of this ecosystem service recorded in each municipality.

As shown in Figure 3 the municipality of Martinsicuro has 45 % of its surface in the first km from the coast, and this area represents the 50 % of the loss in carbon storage detected for this municipality in the period 2012 – 2021. The plans forecasts located in this buffer if totally implemented will represent about the 30 % of the carbon storage loss due to plans forecasts for this municipality. In most municipalities, the coastal strip in the period 2012 - 2021 records the loss of carbon storage with a peak for the municipality of Francavilla.

From these results it is clear that the new urbanization areas are strongly responsible of probable future changes in carbon storage, specifically the expected losses are many times higher than the one measured by the model for the 9 years from 2012 to 2021.

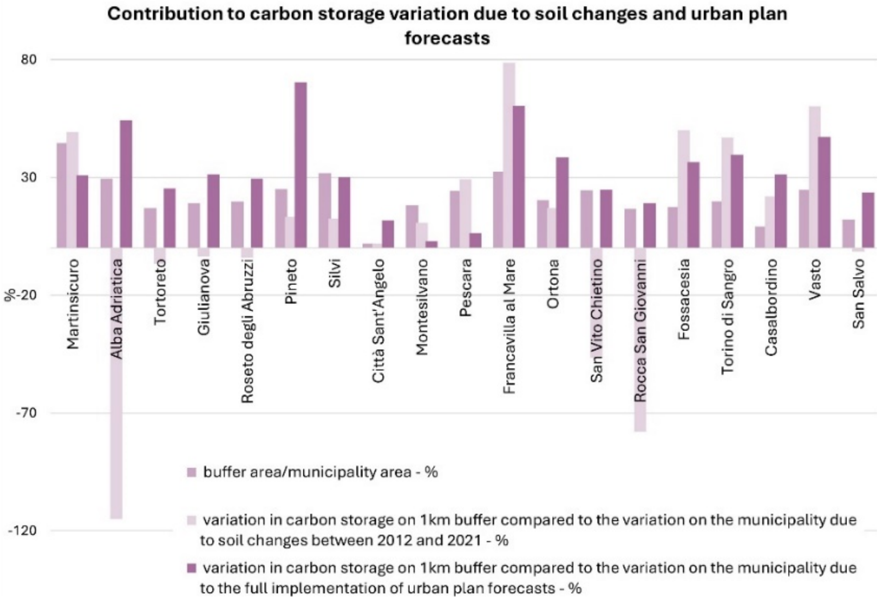

Figure 3 – Contribution to carbon storage variation due to soil changes and urban plan forecasts in 1 km buffer from the shoreline.

The second considered ecosystem service is the one of agricultural loss. Also, in this case the study is carried out both for the 19 municipalities and for their buffer of 1 km from the shoreline. The agricultural surface from 2012 to 2021 decreased and will continue to decrease if urban plans will be implemented. Specifically, the crop production that in 2012 is 234 million kg decreases to 233 million kg in 2021 and it will decrease to 211 million kg with the full implementation of urban plans. The last one will generate an economic loss of 4,5 million €/year that is 40 times higher than the one recorded between 2012 and 2021 (about 100 000 €), with the coastal belt that determine about 30 % of the total economic loss. The plans categories determine about the same contribution to that finding (33 % of the total for each one). This kind of analysis has been done for each municipality too. Figure 4 shows that in all the municipalities the crop production decreases from 2012 to 2021 and will continue to decrease with the full implementation of the plans and this is true also for the 1 km buffer. Some municipalities have low or not economic loss due the fact that not a lot of agricultural areas are in the coastal belt (i.e. Città Sant'Angelo, Montesilvano and Pescara) since these areas has been urbanized during the years particularly during the 60's and 80's [17].

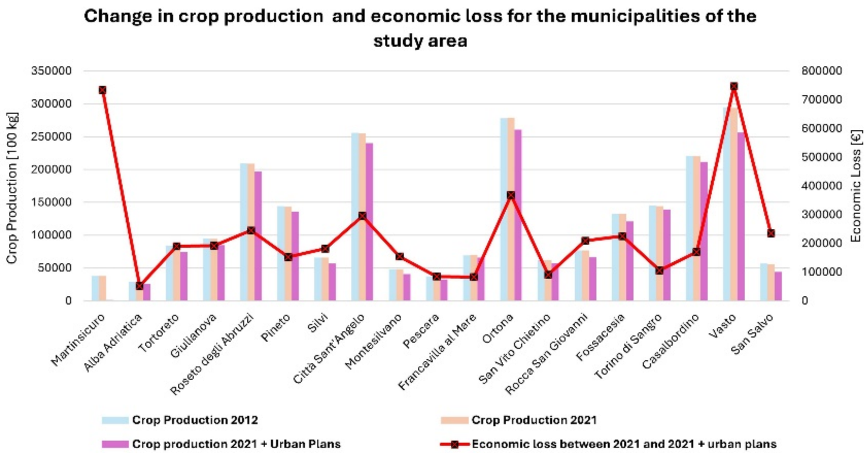

Figure 4 – Variation in crop production and in economic value for the municipalities of the study area. In light blue there is the crop production for 2012, in pink the one for 2021, in dark pink the expected crop production after the full implementation of urban plans forecast. The red line is the economic loss due to the changes in land use between 2021 and the implementation of the plans (2021 + urban plans).

The last ecosystem services considered is the water storage of soil. As declared in the methodology the water retention capacity of the soil change with the soil land cover and use. The higher is the impermeabilization rate the lower is the capacity of the soil to retain water. Specifically, as shown in Table 5, for this study the equivalent runoff coefficient (φ eq) has been calculated, and it result that in 2012 it is equal to 62,3 %, 62,4 % in 2021 and will become 63,5 % with the total implementation of urban plans forecasts. Value like that means that about the 60 % of the water become runoff and will not be retained by soil. The situation is more serious for the coastal belt in which the coefficient reached the 66,5 % with the total implementation of plans.

Table 5 – Equivalent runoff coefficient (φ eq).

Reference year	φ eq all the municipality surface	φ eq for 1 km buffer
2012	62,3 %	64,05 %
2021	62,4 %	64,07 %
Urban plans implementation	63,5 %	66,5 %

The study of each municipality shows that the value of φ_{eq} between 2012 and 2021 is similar, they differ only in few cases and the difference is very low (about some decimal). The absolute values of φ_{eq} can be read in Figure 5. It results that for 2021 each value is higher than 50 % this means that for all the municipalities at least 50 % of water becomes runoff and need adequate sewages to be managed.

The higher value is recorded for Pescara (about 70 %). After the plans implementation the situation changes. As shown in Figure 5 the cases in which φ_{eq} is the highest are Martinsicuro (>70 % both in the municipality and in the coastal belt) and Montesilvano. The cases of Torino di Sangro and San Vito Chietino are particular. They are the only municipalities in which the φ_{eq} on the coastal belt after the plans implementation is lower than the whole municipalities. In fact, generally, the coastal belts are more sealed than the other areas and consequently the water retention capacity is lower.

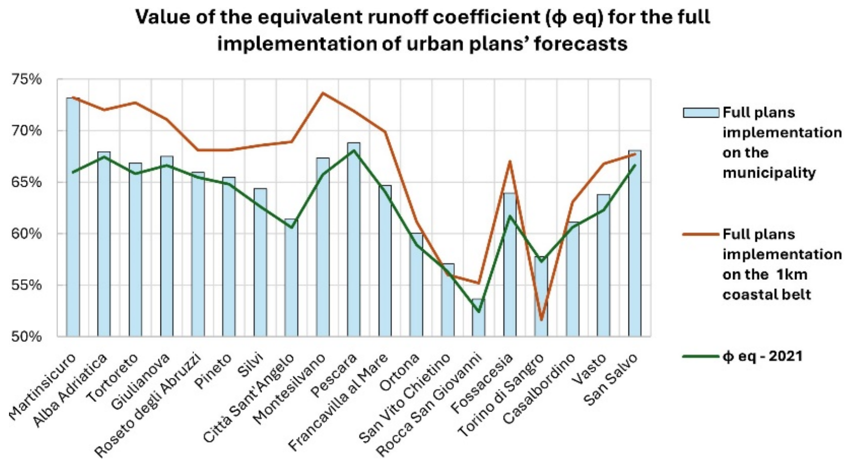

Figure 5 – Value of the equivalent runoff coefficient (φ_{eq}) for the full implementation of urban plans' forecasts calculated both for the whole territory of each municipality (in light blue) and for the buffer of 1 km (orange line). The green line represents the equivalent runoff coefficient for 2021 for the whole municipalities surface.

Discussion and Conclusion

The Adriatic coast certainly represents one of the most urbanized coastal areas in the Mediterranean basin. Today, the presence of important ecological values and ecosystem services clash with an ever-increasing anthropogenic pressure that, being seasonally adjusted, manifests its tangible effects over narrow time spans. Yet, this is an area, as seen for Abruzzo, that still has high ecological values of primary importance. The knowledge of which landscapes are the richest in carbon would help, for example, local governments in defining effective target incentives for landowners in exchange for forest conservation. Assessing ecosystem services is necessary to develop spatial planning scenarios and ex-ante evaluation of policies. Furthermore, in this way it is possible to consider the level of well-being of society and provide policymakers with tools to monitor and improve well-being. [1]. Decision-makers must equip themselves with cognitive and managerial tools capable of considering in spatial planning tools the ecosystem service and distinguishing the different areas of interest and relevance and knowing the interrelations at different spatial-temporal scales. Decision makers and the population should become more aware of the economic value of ecosystem goods and services, which, once destroyed, are sometimes impossible to restore or often are, but only at very high costs [23]. Increasingly, however, the initiatives that take place from year to year are aimed at ensuring the presence of the sandy shore (beach nourishment, coastal defense structures) to safeguard the economic spin-off generated by seaside tourism that represents one of the main sources of the local economy. As repeatedly observed, the absence of a strategic vision for the management and protection of these areas leads municipalities to increase urban loads in the territories involved and in the first kilometer from the shoreline. As mentioned, however, insufficient attention is paid to the influence such transformations could generate on coastal dynamics and fragile existing residual ecosystems [14].

The analyses on the transformative forecasts of municipal urban plans es made it possible to estimate the amount of potentially usable land for urban purposes, and to quantify, albeit with simplifying but effective assumptions, the impacts produced in terms of loss of agricultural production, carbon capture and storage and water retention. The knowledge of the transformative forecasts of urban plans is crucial for the identification of possible critical issues, for planning targeted corrective actions, and for the achievement of the important goals of Agenda 2030 [4]. As is often the case, the economic interest associated with urbanization is greater than that associated with other types of use. In general, urbanizing agricultural land is less costly than intervening in degraded areas or disused infrastructure [2].

Finally, it must be noted that the techniques and tools available make it possible to draw up highly detailed urban planning frameworks, but political measures often do not go beyond the borders of the administrative municipality unit. In addition to the already existing coastal protection plans that, it should be remembered, involve the territory of a single region, it might be advisable to start thinking about strategic plans that cover the entire physiographic unit and that can actively influence the location of new urban forecasts not only because of the possible physical risk but also because of the effect on sediment transport and erosion dynamics.

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ECOSYSTEM SERVICES AS SUPPORT TOOL OF URBAN PLANNING ACTIVITIES IN COASTAL AREAS

Annunziata Palermo, Lucia Chieffallo, Natalia Rispoli

Abstract: In coastal areas, increased climatic and anthropogenic pressures contribute to the reduction of ecosystem services related to the biodiversity of natural capital. These dynamics make the coastal areas one of the most complex contexts in which to combine the needs of environmental protection and those that characterize the government of the territory. Given these assumptions, this research activity intends to define the "Blue Community" model. It is aimed at directing planning processes in the definition of the rules of local resources' use increasing coastal ecosystem services. In order to guide this research, a Systematic Literature Review (SLR) on the role of ecosystem services in urban planning was conducted. The paper presents the first results of the SLR. In particular, quantitative analysis has made it possible to derive information relating to sources, authors and keywords, highlighting the growing recent interest on the research topic. Instead, the qualitative analysis based on the adoption of a technique of cluster analysis has favoured the study of the interrelations between planning activities of the coastal settlements and the ecosystem services.

Keywords: coastal areas, ecosystem services, urban planning

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Annunziata Palermo, Lucia Chieffallo, Natalia Rispoli, *Ecosystem services as support tool of urban planning activities in coastal areas*, pp. 473-483, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.43

Introduction

Starting from the commonly recognized definition of ecosystem as a system characterized by the biotic component and the abiotic component, Morri and Santolini (2013) state that "ecosystems have in themselves the potential to preserve life, stabilize soils, control the cycles of the elements (atmospheric and water), buffer extreme phenomena (temperature, humidity, precipitation, etc.). This dynamism, characterized by cyclicity and reciprocal subsidiarity with the neighbouring ecosystems, allows a better adaptation to the global factors of change and makes natural and anthropic systems less vulnerable and more resilient" [17].

Sharing this position, it is evident how the anthropogenic pressure and all the activities that interact with the ecosystem balances determine a reduction in the number of species and habitats and, therefore, a progressive loss of natural capital, which forms the basis for social welfare and sustainable economic development. In this regard, the term "capital" demonstrates how, alongside the intrinsic value of the environment, some aspects related to its economic importance can be identified. Indeed, the notion of natural capital has been instrumentally borrowed from the economic sector to indicate the value in physical, monetary and welfare terms offered by biodiversity to humanity, also in order to guide the choices of public decision-makers with specific regard to urban and spatial planning activities.

Among the natural elements that play an important role in meeting the needs of citizens, the coastal system is considered to be one of the main, as it favours the extension of trade and human settlement, as well as numerous indirect ecosystem-related functions. Therefore, the coastal system represents a strategic resource in the experimentation of new territorial policies and planning that bring advantage to the settled population keeping the ecosystems in an efficient ecological state. Specifically, the benefits of the coastal system can be classified according to the ecosystem services categories [6, 11] proposed by the Millennium Ecosystems Assessment (MEA) [16].

MEA is an international research project, undertaken in 2000 and concluded in 2005, which proposes a classification of ecosystem services in four categories: provisioning, regulating, supporting and cultural service. Among these, the categories regulating and cultural services are of particular interest for the research, including benefits that concern, for example, environmental protection and climate regulation [2, 10, 14, 15] and the intangible benefits that people obtain from ecosystems such as tourism, seascapes, health and well-being, creativity and art [4, 9, 13, 21].

With regard to the coastal areas, which offer innumerable benefits in terms of quality of life, it should be stressed that they are characterised by specific elements of complexity and present numerous challenges, for example, due to the presence of fragile ecosystems, different intensive socio-economic activities, inadequate anthropogenic processes of urbanization, as well as natural dynamics of climate-related erosion. In particular, in recent years, the alteration of marine and coastal ecosystems is internationally growing because of the complex interaction between anthropogenic and climatic pressures, such as rising sea temperatures that can cause waves of sea heat, increasing frequency of extreme weather events and acidification of the oceans. Therefore, the international scientific community is progressing in designing and testing different approaches and methodological tools for a solid assessment of the impacts arising from the action of these multiple pressures that simultaneously affect coastal zones and related ecosystem services. These efforts are aimed at finding the right balance between the actions of environmental protection of the coastal areas and those of settlement and redevelopment of urban infrastructure and services, favouring an integrated and sustainable territorial planning.

In particular, sharing these aims, this research activity is oriented to the definition of the “Blue Community” model. It looks at coastal areas as a place of experimentation of innovative planning strategies, the integrated and sustainable management of the urban-maritime and local environmental heritage. Therefore, the following are the first results preparatory to the definition of the above model. They regard the definition and application of a Systematic Literature Review study to investigate the interrelationships between coastal settlement planning and design activities and ecosystem services. This deductive approach makes it possible to define a theoretical framework on the research topic, which is the essential reference point for the future development of the research, also in order to take account of any empirical aspects.

Materials and Methods

Intercepting the scientific research carried out at the international level through the application of a Systematic Literature Review is useful in order to deepen the definition and methods of measurement and evaluation of coastal ecosystem services. In fact, it is a technique that allows to identify, select, critically evaluate and summarize current knowledge in a research field.

Therefore, the Systematic Literature Review provides a theoretical framework for identifying trends in existing literature and for identifying gaps and inconsistencies in research on the issues under consideration at the same time. To conduct an accurate Systematic Literature Review and minimize the risk of distortion, undertaking a standardized and reproducible scientific methodology recognized at the academic level is crucial. It is divided into the following phases.

The first phase concerns the identification of the research topic that concern the issue of ecosystem services in urban planning, with particular reference to coastal services.

The next step is the definition of the research question, ensuring that it is clear, targeted, concise, complex and questionable. In this case, the following research question is considered: “What are the main lines of research on ecosystem services in the context of urban planning?”.

From the above research question, it is possible to extract the keywords in order to form the query string and start the search of documents on the selected database, which is Scopus. In the query string “ecosystem service AND urban plan”, the operator “AND” allows to connect the two concepts, so that the database returns in response all indexed documents that contain both words entered.

In order to refine the research, Scopus offers a wide range of useful options to further narrow the list of results. Therefore, it is possible to set criteria to include-exclude documents. In this case, only articles in English and open access format are chosen.

The next step is to extract the relevant data from the selected publications, which in this case consist of 757 documents.

After that, the eligibility of the data is assessed by submitting the documents to a first review through the reading of the abstracts and of the main contents.

The last phase consists in the bibliometric analysis of the relevant data characterizing the documents, to obtain a complete overview of the scientific research carried out on the topic.

In the end, this study made it possible to summarize the quantitative and qualitative information of the publications collected, through a series of maps, tables and graphs.

Results

The results of the bibliometric analysis may be divided into quantitative and qualitative data.

The quantitative ones, deduced thanks to the use of the Rstudio's Biblioshiny package, have allowed to summarize the distribution models of publications over the years and explore their impact on the scientific community. In particular, 757 documents published in the period 2005 to 2023 were collected. Figure 1 shows the time course of publication of these documents.

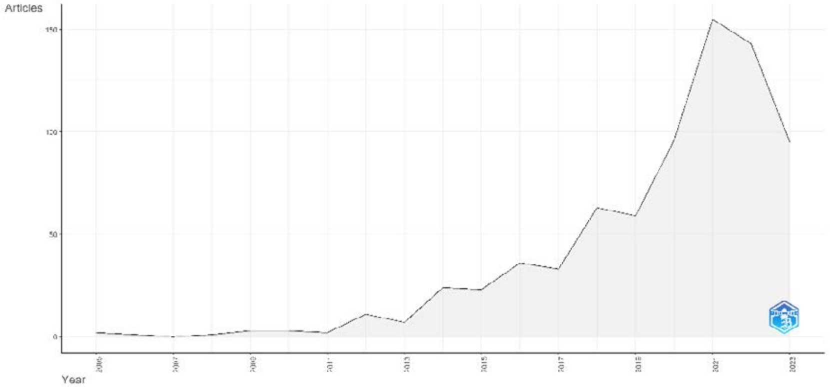

Figure 1 – Time course of publication of the selected documents.

In general, the graph shows a curve with increasing trend, so the scientific documents related to the topic have increased with time and consequently also the interest on the role of ecosystem services in urban planning. The peak of the chart was reached in 2021 with a number of publications exceeding 150 articles. In the following years, despite the curve shows a slight decrease, the articles published are in high numbers: just under 150 in 2022 and 2023 are about 100.

The documents are derived from 206 sources and have an average citation of 30.98, while the total references amount to 47 290. The authors of the documents are 2659 and most have worked in collaborations, which for 33.16% are international. The documents come from 88 countries, although most of the publications were produced in China and in the United States. The European countries that exceed 100 publications are the United Kingdom, Italy, Germany, Sweden and Austria.

3276 keywords plus have been identified, that is keywords that appear frequently inside the documents, while the sum of the keywords identified by the authors is equal to 2330.

Subsequently, a qualitative analysis was launched to gather information on the content of the documents. Qualitative analysis is a process of study of publications through techniques of correlation and co-occurrence between keywords, aimed at obtaining significant results of synthesis represented by thematic clusters.

This type of analysis was carried out using the VOSviewer software, a tool for building and displaying bibliometric networks. In particular, the network extrapolated from the selected literature is the "Network Visualization", reported in the following Figure 2.

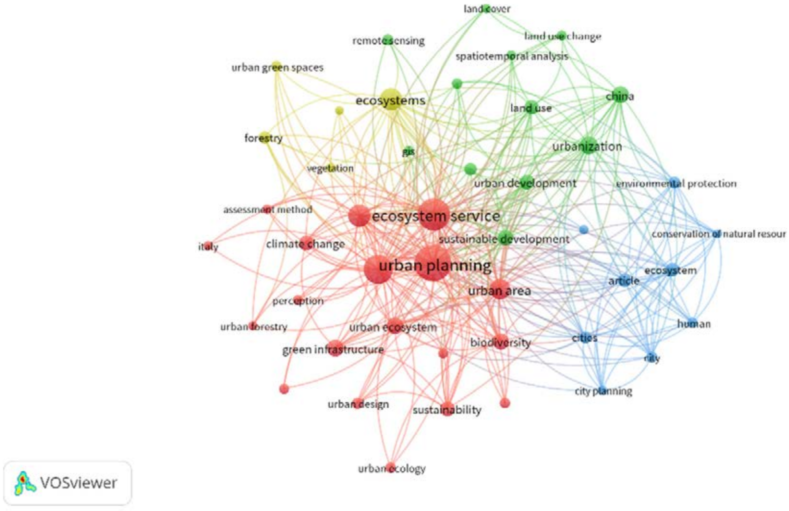

Figure 2 – Network Visualization.

The Network Visualization is composed by a series of nodes on which the major keywords from the 757 documents downloaded by Scopus are labelled. The size of the nodes reflects the frequency of presence of keywords in the documents and the proximity of terms in the map is directly proportional to their correlation.

Therefore, the closer the terms are to each other, the greater the frequency with which they occur simultaneously in the documents.

The main feature of Network Visualization is the colour subdivision that allows you to visually define thematic clusters. In Figure 2, clusters are distinguished by four different colours:

- the red cluster is called “assessment methods of urban ecosystem service” [18, 20];
- the green cluster is called “spatio-temporal analysis of land use and urban growth” [1, 24];
- the blue cluster is called “conservation of natural resource and environmental protection” [3, 12, 22, 23];
- the yellow cluster is called “ecosystems in urban green spaces” [5, 8, 19].

Discussion

The quantitative results of the Systematic Literature Review revealed a strong increase in interest in the research on ecosystem services in the context of urban planning, although the number of documents focused on coastal areas is quite small. Nevertheless, the same have been used to carry out an analysis on the link between the same and the different clusters emerged.

Considering the first cluster, in particular the study of Portman *et al.* (2016) proposes to identify the level of protection of coastal areas in order to ensure the effective management of ecosystem services. The classification is carried out by combining two values. The first one is obtained from questionnaires administered to stakeholders, who have assigned a score in relation to the value of the landscape and activities. The second one is obtained from the quality of the physical attributes of the areas, based on biotic and abiotic elements. Based on the data obtained, the authors define three protection scenarios highlighting the need for stricter procedures within the areas closest to the coast because of the presence of more ecosystem services [18]. The assessment of such ecosystem services may be carried out through software. Among these, the most widely used internationally is “Integrated Valuation of Ecosystem Services and Tradeoffs” called InVEST. In fact, it is used in most of the articles aimed at quantification and mapping of ecosystem services, as well as comparison of scenarios, economic evaluation, land and resource management, impact assessment and policy development [7]. A sample application of InVEST models is presented by Salata and Arslan (2022). Their research aims to demonstrate how digital modelling of ecosystem services can be used practically to design sponge districts and measure the benefits of performance-based solutions. In fact, the first important step of the research was to measure the risk of floods in the area, through the InVEST’s model called “Urban Flood Risk Mitigation model”. The results of this modelling are used to assess the biophysical distribution of the outflow and its retention throughout the city of Izmir, Turkey [20].

Considering the second cluster, in particular Zhanget *et al.* (2022) propose a mapping of land use change and spatial distribution of ecosystem services values from 1989 to 2018 in the six districts of the coastal city of Xiamen, China. The results of the research show the conversion of agricultural land and river basins into built-up areas, especially in the period between 2000 and 2010. In this period, the authors highlight a loss of about 70 million CNY of river basins followed by the loss of about 50 million CNY of agricultural land, aggravating urban challenges such as the heat island effect, traffic congestion, housing strain, environmental pollution and lack of urban greenery [24]. The increase in urbanisation at the expense of ecosystem services is also addressed in the article proposed by AlQahtany *et al*. (2022). The case study analysed concerns the metropolitan area of Dammam, located along the east coast of Saudi Arabia. Here the extent of coastal land reclamation is assessed through the use of satellite imagery to compare the coastline boundary of the study area from 2000 to 2020. The analysis of five major reclamation projects showed that the total surface area of water and marine vegetation is between 66.5 % and 100 %, for a total of 6081 hectares of reclaimed land in the Arabian Gulf. The research focuses on the importance of these practices to highlight the implications in terms of sustainability, namely the loss and damage to biodiversity and ecosystem services. The article concludes by highlighting the need to undertake sustainable coastal environmental management through the regeneration of wetlands in coastal areas to restore lost ecological services. Although, according to the authors, it may be difficult to reduce the degradation of marine habitat and ecosystem if coastal remediation continues [1].

Considering the third cluster, some documents propose the combination of urban planning and ecosystem services generated by the species to be safeguarded. For example, Thomson *et al*. (2022) deal with the regeneration of the city of Perth, located on the Swan Coastal Plain in Western Australia, which is a hot spot for the biodiversity it hosts. The authors, based on some examples, developed principles of urban design, called “cockatoo friendly”, with the objectives of increasing the city’s ability to support endemic species, improve associated ecosystem services, increase urban resilience to climate change to strengthen community and institutional support for nature-positive design and development [23]. Likewise, Brodie *et al*. (2020) propose the analysis of coastal planning of the vulnerable area of developing States of the small islands of the Pacific, to reduce anthropogenic pressures that threaten local biodiversity. The latter provides a wide range of ecosystem services, including food supply, water purification and coastal protection. Therefore, a number of priority actions are proposed in the document with a view to improving the conservation of the marine habitat, enhancing climate change resilience and the related ecosystem services [3]. In addition, Sutton-Grier and Sandifer (2019) analyse the value of conservation of coastal ecosystems for the protection of biodiversity, for the reduction of impacts and for the promotion of human health and well-being. Specifically, the authors identify a range of ecosystem services provided by coastal areas, focusing on the significant role of coastal ecosystems in reducing the risk of storms, floods and erosion, highlighting how these benefits turn into substantial economic value for coastal communities. To confirm this theory, the study published in 2017 [22] highlights how coastal wetlands had avoided direct damage for 625 million dollars during Hurricane Sandy. Therefore, the authors recommend to act in the pre-disaster phase by adding a section Nature-Based Solutions (NBS) to the emergency preparedness plans. The NBS contribution is also analysed in Hughes *et al*. (2022). These authors also provide the definition of NBS by the International Union for Conservation of Nature (IUCN), or "actions to protect, sustainably manage and restore natural or modified ecosystems that address social challenges effectively and sustainably in an adaptive manner, while providing benefits to human welfare and biodiversity". On the basis of this definition, three types of NBS are proposed for marine environments: the improvement of the use and preservation of protected natural aquatic ecosystems; the active restoration of degraded habitats; the creation of new ecosystems regulating nutrients through aquaculture [12].

Considering the fourth cluster, Chen *et al*. (2002) propose a study to verify the direct and indirect effects of urbanization on vegetation productivity. At the centre of their research are 48 cities located along the coastal zone of eastern China. The results showed that the direct effects relate to the significant loss of urban vegetation areas as the intensity of urbanisation increases in all cities examined. In contrast, indirect effects of urbanisation on the productivity of urban vegetation vary between cities depending on local climatic conditions [5]. The relationship between urban greenery and climate in coastal areas is also analysed by Rodrigues *et al*. (2023). Specifically, the study proposes a methodology for the implementation of green infrastructure with the aim of offering ecosystem services that mitigate the impacts caused by climate change in the districts of Pirambu, in the Brazilian city of Fortaleza. Four types of green infrastructure have been proposed combining decision-making analysis for the choice between different types of green infrastructure and spatial analysis of data through geoprocessing software. They are multi-purpose roads, rainforests, Permeable flooring and soil bioengineering.

The location of each of them has resulted in benefits for the environment and for the ecosystem services offered linked to global warming [19]. The importance of green and blue spaces for biodiversity and human welfare is analysed in Fisher *et al*. (2021). The document examines how the diversity of animal species in the coastal green and blue space in Georgetown (Guyana) is associated with people's welfare, through questionnaires and point counts [8].

Conclusion

At the international level, the debate on the ecological transition alludes to a process of technological innovation and environmental revolution, aimed at encouraging socio-economic development also in terms of territorial governance while respecting natural balances. Therefore, one of the most concrete areas of experimentation of the ecological transition is urban and territorial planning. It fosters the sustainable and resilient development of territories through a balanced management of their natural resources. In this regard, ecosystem services have long been insufficiently targeted by sectoral programmes and policies. However, they have recently been rediscovered, especially in the field of sustainable planning, as confirmed by the results of the quantitative analysis of the proposed Systematic Literature Review.

In particular, this study analysed the relationship between ecosystem services and urban planning in coastal areas that are subject to processes of urban expansion on average more intense than internal areas. This study was carried out in order to orient the first phases of the authors' research aimed at defining a planning model, called "Blue Community". It supports the integrated management of ecosystem services and urban heritage to improve the sustainability and coherence of urban and spatial planning choices. This aim is particularly relevant because of the recognition of ecosystem services as a dominant issue in the policies of mitigation and adaptation to climate change, the protection of ecosystems and biodiversity and socio-development of the established communities.

Going into the merits of the discussion of the results obtained, compared to the 757 documents analysed, it emerged that a small number deepens the research topic with reference to coastal areas. Specifically, the qualitative analysis allowed to deepen the content of these documents, also through the application of a cluster analysis technique, from which four thematic clusters emerged.

The first cluster showed a growing interest in new methods of evaluating ecosystem services, or, on the one hand, the combination of socio-economic and environmental aspects in the analyses and, on the other hand, the utility of mapping ecosystem services through open-source software InVEST.

The issue of mapping ecosystem services is also addressed in the second cluster, which focuses on spatial-temporal analysis of land use and urban growth, highlighting the importance of this type of study to point how the urbanization of territories translates also in losses of the values of ecosystem services in economic terms and not only into almost irrecoverable loss of biodiversity and habitats.

The third cluster focuses on the activities of conservation of natural resources and protection of the environment by addressing in an integrated way studies that concern the protection of habitats and biodiversity typical of marine territories that can be implemented with different types of NBS.

Finally, the fourth cluster includes studies that highpoint how ecosystems in urban green spaces within coastal areas are important because they can contain the negative effects of urbanization, and combating the consequences of climate change, including by providing benefits for habitats and in terms of quality of life.

From a more general point of view, the study summarised here raised awareness of the need to integrate environmental issues into territorial policies. In particular, it allowed to identify definitions and methodologies for measuring existing coastal ecosystem services, quantitative benchmarks, access to platforms and software implemented for this purpose, and to start an initial analysis of the main intervention tools characterizing these contexts and aimed at combining conservation and development needs. These elements underline the importance of taking a multidimensional approach to assessing ecosystem services, with regard to urban and spatial planning activities in coastal areas, that is both necessary and strategic in terms of sustainability and resilience.

From an operational point of view, for example, the importance of using geospatial data from satellite applications and digital instruments has emerged. They produce information layers that can be easily imported into the GIS environment to evaluate the state and evolution of the inhibitory and driving factors of ecosystem services and, consequently, address data-based urban planning applications. These applications, aimed at the integrated and sustainable management of the coastal strip, can be oriented, based on local needs, for example, to the protection and enhancement of natural emergencies, the recovery of urban and economic decommissioning and greater cohesion between local government and coastal communities. In this regard, although studies on the assessment and mapping of ecosystem services are numerous, they do not seem to find a stable and codified place in the processes of planning of local scale and large area to date. Recognising this gap, the future developments of this research will be aimed at supporting planners in defining rules for the ecosystem use of coastal areas also on the basis of the studies summarized in this contribution, for example by providing them with an integrated information base through the implementation of a GIS geodatabase fed by updated and interoperable data at the appropriate geographical scale from which to deduce appropriate ecosystem indices.

In conclusion, there is a need on the part of urban and territorial planners not to confine the assessment of ecosystem services to the sphere of pure environmental accounting, but to consider it as a tool to support the definition of new development models, preserving the environmental components and triggering ecosystem dynamics of territorial rebalancing. In this sense, coastal ecosystem services represent a driver of sustainable and compatible development with the ability of ecosystems to preserve themselves over time.

Acknowledgements

These studies are also attributable to the research activities funded by D.M. No. 118/2023 (Next-GenerationEU - National Recovery and Resilience Plan).

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LIVING IN A FRAGILE AND DYNAMIC TERRITORY: THE CONTRIBUTION OF ENVIRONMENTAL AND ARTISTIC MEDIATION TO THE APPROPRIATION OF NEW WAYS OF LIVING IN COASTAL AREAS

Camille Provendier

Abstract. The research focuses on identifying the levers and scope for progress of environmental and artistic mediation in raising awareness among users to changes in the way coastal areas are inhabited. The research is based on a contemporary and forward-looking approach, grounded on the heritage approach and the memory of practices in the area to encourage citizens to take action concerning environmental issues.

Observing and understanding of the landscape help to change our relationship with the world by rethinking the relationships between living and non-living beings. The contribution of knowledge and representations that promote awareness are at the heart of the political recomposition of the Anthropocene.

This research is part of a multi-scalar and transdisciplinary spatial dynamic, touching on local cultural policies society and academia. The commitment of local and institutional players to the approach bears witness to a participatory and situated research, capable of perpetuating links between the arts, sciences and society in a co-production of knowledge.

Keywords: Raising awareness - Environment - Landscape - Arts & Sciences - Coastline

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Camille Provendier, *Living in a fragile and dynamic territory: the contribution of environmental and artistic mediation to the appropriation of new ways of living in a coastal areas*, pp. 484-495, DOI: 10.36253/979-12-215-0556-6.44

Introduction

Our initial research question is based on the ability of observing and understanding the landscape, as a reflection of the evolution of spatial practices over time, to contribute to changing our relationship with the world. We postulate that the contribution of knowledge and the nourishment of representations contribute to the awareness of individuals. Combined with experimentation and active discovery, they encourage people to take on board the messages and get involved in environmental issues linked to the necessary changes in ways of living.

In the current context of fragility of coastal areas linked to global change, it is necessary to make the dynamics of the landscapes in which they live understandable to as many people as possible. In contrast to catastrophist or ex nihilo approaches, mediation based on inhabited territories that is accessible and sensitive proposes the creation of a common heritage shared by residents and visitors alike.

We have chosen to mobilise the experiential and playful approaches as the basis for our empirical research, by re-examining the messages, the methods of transmission and awareness-raising, and the formats for disseminating information. The aim of exploring the effects of these different approaches on the perception of the landscape is to reach as many coastal users and residents as possible, and to encourage them to renew their vision of the world around them. To achieve this, we have developed a number of environmental and cultural mediation systems accessible to a wide range of audiences.

The challenge of transmitting thematic and educational messages via media for promoting landscape heritage has led us to question the systems for producing scientific and interpretative data and the relevance of their distribution scales. The effectiveness of local project dynamics, driven by bottom-up and/or top-down initiatives, is also a central analysis criterion in our experiment.

The diversity of the scenarios aims to enrich the resources traditionally used in environmental education, by highlighting the potential for raising awareness of the artistic approach through aesthetic emotion. We are interested in the emotional approach and the cognitive processes it generates, particularly in the processing of information likely to trigger civic action.

The aim of this research is to identify and evaluate the levers and scope for progress of environmental and artistic mediation in raising user awareness of changes in coastal practices and ways of living sustainably. The proximity felt by the population with the landscape, whether aesthetic, cultural and identity-related or affective and sensitive, gives it a strong potential for raising awareness. We have sought to identify the most effective means of encouraging a broad-based public response through raising awareness of the future effects of global change on the coastline.

Materials and Methods

Our case study, developed within the Heritage and Archaeology department of *Sète agglopôle Méditerranée* (SAM), looks at ways of raising awareness among local populations and users of coastal areas of the changing ways in which coastal areas are inhabited. The project is likely to be of interest to those involved in regional planning, who are increasingly involved in implementing public policies aimed at changing the way these sensitive areas are understood and used.

The challenges of bringing science and society together require a locally rooted geographical and social context in order to improve the ability of university research to find viable solutions that contribute to the habitability of the coastal area of the Thau Basin. This contrasting area, which is both fragile and dynamic from a geomorphological and climatic point of view, has a growing population due to its strong economic and tourist appeal. The issues of acceptability are therefore at the heart of the objectives of disseminating a culture of risk inherent in the public service missions carried out by local authorities.

The notion of the spirit of place (*genius loci*) and the artistic expression of the relationship with the landscape are expressed through residencies for visual artists hosted by the local authority's heritage network facilities. In this way, they renew the treatment of their message around the key themes of the evolution of landscapes, skills, agricultural practices and the relationship with the environment as a resource since Antiquity. This heritage and landscape approach to the area and its evolution implies a cross-disciplinary, multi-faceted and multi-disciplinary enhancement, particularly through the promotion of geo-heritage, which contributes to the culture of risk in the age of the Anthropocene [11].

The Heritage and Archaeology Department offers artists in residence the opportunity to express a sensitive and unique relationship with the coastline and its landscapes. We have identified the *MangeNuage* sailing circus company to develop the *Messagers du littoral* (Coastal messengers) project, our case study. Their proposal carries a strong message about soft mobility, with the use of wind as propulsion energy, and a reflection on the footprint we leave on the coastline, in the way the ship lands on the beach but also in the image of lightness conveyed by the aerial gymnastic apparatus (trapeze, fabric, etc.). As part of the Arts & Sciences residency, the project will be enriched by a scientific and educational approach to landscape and geoarchaeological mediation.

The methods used are based on the human and social sciences. Theoretical reflection is based on the concepts of inhabitation [16], environmental education [14] and the ecomuseum approach [17] in order to address the transdisciplinary issue of raising awareness of changes in coastal practices. We carried out empirical work based on interviews and participant observation [4], with the aim of understanding the day-to-day relationship between individuals and changes in the surrounding environment. This methodological approach aims to fuel the representations of users of coastal areas to enable them to make informed choices in terms of adapting their ways of living.

Initially, we felt it necessary to take stock of the situation by collecting and analysing qualitative data on how landscapes are perceived by their users, using an approach that was sensitive, memorial and forward-looking. The results were then used as a basis for the development of media and mediation tools, the messages of which contribute to social representations of the environment and climate change issues. Finally, concrete information was gathered through participant observation, with the aim of experimenting with the Arts & Sciences approach on coastal fragility and the impact of our use of space on the evolution of landscapes (figure 1). These data have contributed to the development of an intervention methodology for use by local authorities as well as scientific and artistic groups that can be mobilised in projects combining the arts, sciences and society (figure 4).

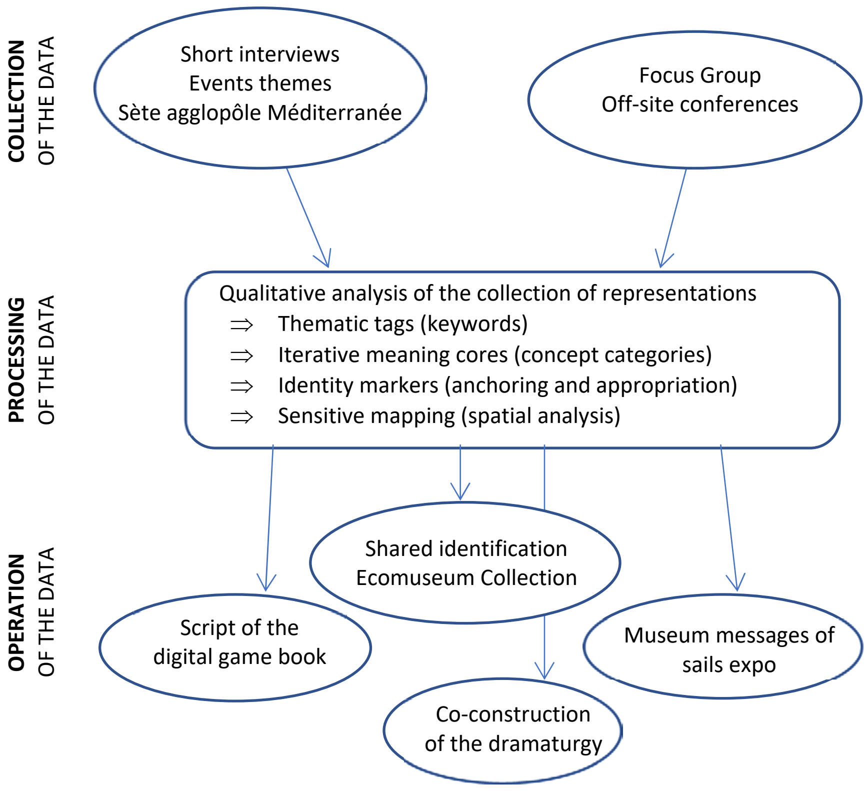

Figure 1 – Qualitative data itinerary: collection - processing – operation.

Results

A methodological experiment was set up to bring together people involved in environmental education and performing arts. A technical and financial partnership with *SAM*'s Heritage and Archaeology Department enabled several creative residencies to be organised with the *MangeNuage* Company. At the end of two years' work, the show *Ressac*, inspired by the questioning of the relationship that contemporary societies have with the surrounding environment and the coastal space in particular, was presented on the lagoon shores of the Thau Basin. Scientific and environmental mediation tools were also tested as part of multidisciplinary theme days. On these occasions, live performance and active education have been combined to spread a common message using artistic, entertaining and educational approaches. Reaching out to individuals while arousing their curiosity is as much a challenge, in seeking to link affect and intellect, as it is a powerful potential for appropriating the challenges of changing the way we practise a historically fragile and dynamic coastal area.

The framework of a feasibility study is set out to define the mixed Arts & Sciences creation as a tool to serve the project and the company, but also to promote and enhance the approach within the local authority. The format of this residency is atypical, at the interface between the methods of artistic creation, cultural policies, heritage enhancement and environmental awareness. The aim of this preliminary study is to analyse the relevance of the project and to examine its feasibility in artistic, media, technical and financial terms. The company's participation in the *Escale à Sète* event then provides an opportunity to publicise the project as it unfolds. The event provided an opportunity for experimentation and creativity, with the clown meeting the audience and working on his posture, a conference-show on the theme of the surf, a presentation of the boat-stage project and the creation of a model to be used as a basis for the scenography, and a presentation of the doctoral research project.

Following on from this rich collective production, work is being carried out with the actor and director to frame and explore the clown's posture in greater depth. Carried out as part of interactive semi-directive interviews, the elements of reflection contributed by the artists and the researcher will be used to fuel a cross-disciplinary issue. The clown's offbeat stance will play down a guilt-inducing approach to climate change, while at the same time establishing a thematic framework that will then simply be evoked in the show. The naiveté of the character makes him endearing, and the audience identifies with him and follows his emotional path, taking on board his candour and wonder at the beauty of nature, his lack of understanding of the phenomena that govern hazards, his anger at his inability to control them, his guilty despair at the destruction of resources, and finally his resilience in the hope of another possible world (Figure 2). This stance therefore has great potential for mobilising the public's representational system, without having any prescriptive effect on the perception of the issues at stake and the choices made in the face of global change.

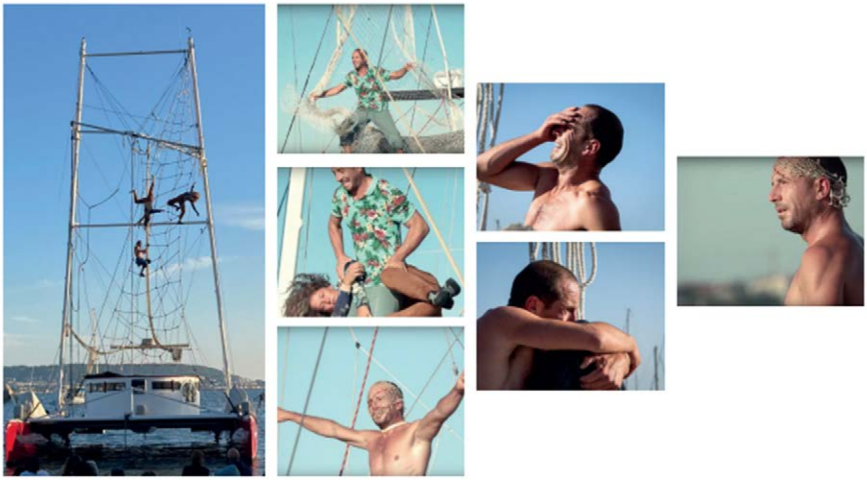

Figure 2 – The clown and emotions in the show *Ressac - Messagers du littoral* (Coastal messengers).

In the same dynamic of creating shared design spaces, an exercise in comparing the dramaturgy with the research orientations and the messages of the mediation devices (table 1) is carried out first by the researcher and then discussed with the artistic team. At this point, the dramaturgy is in an intermediate phase, where the narrative is imbued with strong conceptual and representational imagery that resonates with the scientific and media intentions. This phase offers rich and particularly inspiring material for the Arts & Sciences approach. It must, however, take place before the directing of the actor to inspire it, while leaving room for improvisation, as a space for the artists to appropriate the conceptual approach.

Table 1 – Extracts from the dramaturgy/research crossover table.

III bis: The clown's journey *duration : 3 to 5 min*	Narration : Between here and elsewhere, the journey. But why all this movement? How can you accept a conference with activity and movement in the background? Intolerable! Jean Pink goes off to demand that all activity cease on this boat... How will the clown find his way in the midst of all these possibilities? But when he finally arrived near the boat, just as he was about to ask for calm, a net fell on him and knocked him unconscious.	Appearance of **anger in the clown** => Link between **environmental psychology and the sociology of commitment**: - affects/emotions generate or inhibit action - fear or anger + hope = action The net that knocks the clown out materialises the unexpected **power of wild nature and the fragility of man** in the face of the natural elements, despite the processes of anthropisation and environmental control. => Link with theme 2 of the exhibition: - places man in an ecosystem - highlights the notion of risk

The educational offer has been developed by *SAM*'s Heritage and Archaeology department and aims to pass on a message to users of coastal areas. Playful and educational scenarios help to raise awareness of the richness and fragility of these areas, which are subject to the impact of human settlement patterns. The use of geomorphological, archaeological, historical, geographical and naturalist data reflects the trans-disciplinary approach to heritage used to design the content of the displays. In order to reach a wide audience, mainly teenagers and young adults, a range of scientific and environmental media have been developed (Figure 3):

– a travelling thematic exhibition on the fragility of coastal areas for families, focusing on the challenges of living sustainably in coastal areas. Made up of 3 items printed on Optimist sail, it can also be combined with a round table debate as a time for discussion and citizen mediation on future changes in coastal practices;
– a "mystery trunk": an educational and fun way of solving riddles for a young audience (8-11 years old) based on the escape game principle, the scenario proposes a mission to be solved in a limited time, based on historical content highlighting the riches of the Mediterranean basin. It looks at the issues involved in preserving the natural resources that have contributed to the development of human societies along the coast, and highlights the cause-and-effect relationship between man's actions and the evolution of coastal landscapes;
– a "book where you are the heroine" type of digital game: a fun device for teenagers (aged 13 and over). Based on a multiple-choice scenario, it follows the adventures of an environmental campaigner against a backdrop of international lobbying intrigue. It highlights the impact of knowledge transfer on people's ability to take action. This medium allows us to move from the individual level, by reflecting on our personal practices, to the collective level by highlighting the notion of the Common Good, embodied by the environmental resources and scientific knowledge in the scenario.

Figure 3 – "*Messagers du littoral*" (Coastal Messengers) project scientific mediation tools.

One of the main lessons to be learned from this interdisciplinary experiment is the need to adapt the relationship with time, which varies greatly depending on the players involved. Indeed, appropriating the messages and issues through an immersive experience shared by the various partners and stages in the process (Figure 4) is essential to the development of a credible and reliable Arts & Sciences project, under conditions that are comfortable for all the participants.

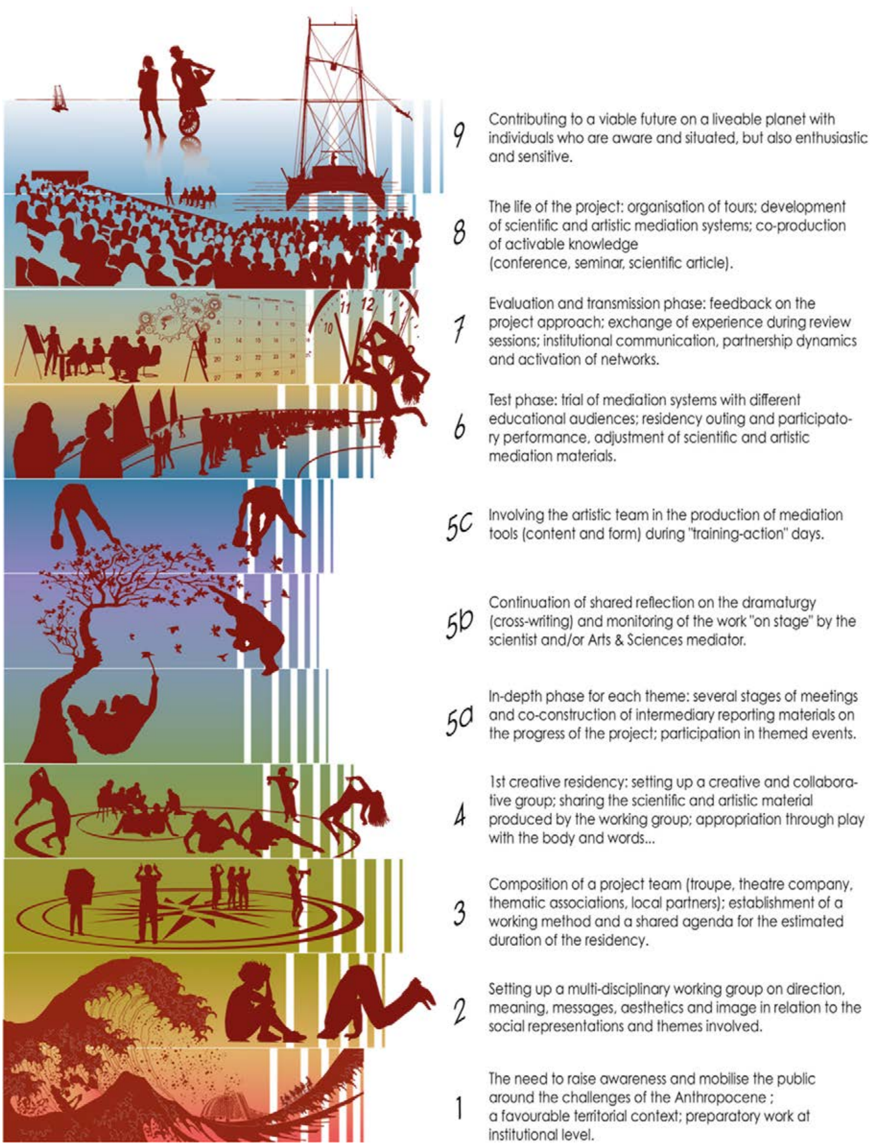

Figure 4 – Methodology Arts & Sciences "*Messagers du littoral*" (Coastal Messengers) project 2021-2023

Discussion

Firstly, we identify three levers for activating a citizen mobilisation through environmental mediation. Firstly, the heritage approach is based on knowledge of geomorphological processes and the capacity to adapt to a resource environment that is mobile and changing, in line with historical climate trends. This memory of how human societies have used the land since the Neolithic period is a valuable asset in the context of adapting ways of living in coastal areas to the effects of global change. It helps to lighten the burden of constraint in the eyes of users by promoting the transmission of a heritage of how to live on coastal shores [11]. Observing the world in which we live sharpens our curiosity about the processes and stories that have helped to shape it. This understanding of phenomena, supported by the "PPF" (Present-Past-Future) approach, enables us to look to the future as a continuity, a creative process in the making, to be welcomed with enthusiasm [7]. The potential of environmental mediation in raising awareness of changes in ways of living revolves around an understanding of the heritage of landscapes and their evolution. It thus contributes to the appropriation of the notion of Common Good through that of the collective cultural heritage of spatial practices by coastal peoples.

The second lever is the pedagogical intention, which places active discovery as the driving force behind the appropriation of content and messages. The stages of this early learning approach are based on experimentation, taking time to build awareness, explore the subject in greater depth and then pass it on. Immersive situations in the field, in action, form the basis of the active pedagogy that developed during the twentieth century [6]. The playful experience is particularly conducive to manipulating concepts and reformulating them in a recreational setting. We have associated with this the objective of feeding social representations of the environment and landscapes as the foundation of the environmental mediation approach. The aim is to deconstruct stereotyped or fantasised visions of a natural environment that is far removed from users' everyday lives, and to encourage a vision of the world as a heritage shared by humans and non-humans on which it is possible to take positive action [8].

Finally, the third and last lever is the role of emotions in the perception of issues linked to global change and in their ability to influence the mobilisation of citizens in favour of a change in coastal space practices. The mobilisation of fear or anger without any correlation to hope generates eco-anxiety, which represents a risk for the mental health and well-being of individuals. So the urgency of helping to trigger pro-environmental behaviour must not mask the psychosocial issues at stake and the journalistic and media excesses denounced by research in sociology [3] and environmental psychology [10]. We contrast eco-anxiety with the strong potential of positive emotions in their ability to generate a collective dynamic of cooperation and commitment to pro-environmental behaviour that is a source of well-being [10]. The sense of wonder generated by a connection with nature is central to our experience of the Arts & Sciences approach.

We have identified elements that trigger this emotion in the landscape immersion offered by the *MangeNuage* company. The shift into dream and wonder is conducive to "situated wonder" [11]. What's more, aesthetic emotion encourages pro-social and pro-environmental behaviour by raising awareness of the political issues at stake through committed artistic creation, embodied by the figure of the clown in *Ressac*. The reflections generated by the show mobilise a representational system that opens up and is enriched, fostering the capacity to act and the ability to make choices as conscious, situated individuals [12].

Secondly, we outline a cross-disciplinary approach - from the point of view of the project approach used in our case study - combining the arts, sciences and society. Fields of activity with methodological and experiential practices that may seem far apart can come together in experimentation and the co-construction of accessible and shared knowledge. This approach to the co-production of knowledge is part of the quest for horizontality that underpins popular education. In this respect, Patrick Geddes is a forerunner in areas linked to regional planning, through the training of individuals and their relationship with the world to which they belong. The academic openness and disciplinary decompartmentalisation that he demonstrated over a century ago invite us to rediscover a civic capacity as part of a process of appropriating our landscape heritage.

The ability of environmental and artistic mediation to recreate links between individuals is illustrated in a remobilisation of citizens that is both individual and collective. The intention is at the political level, in particular in a form of questioning of the social contract expressed by the crisis of representation [2]. The pragmatic approach leads to the identification of a local scale of intervention that can accommodate concrete initiatives conducive to a change in our relationship to property and the related mechanisms of appropriation of environmental resources. Reappropriating the practices of space as a common heritage or inheritance has the potential to bring people together around a shared and sharable resource. If heritage can become the foundation on which the ecological and democratic transition expected by the 21st century can be built, the relevance of the territorial scale as a place or interface for implementing alternatives to the current model needs to be reconsidered. The co-production of knowledge has a strong potential for both disciplinary and relational horizontality, in a sensitive relationship with others. A geographical and social space in which to share knowledge and emotions, a space in which to "build a community" today, can be provided by institutions or members of civil society who are behind local initiatives that function as "laboratories". In this way, the impact of pooling individual commitments in the production of the collective helps to broaden the present and its capacity to intervene in a future that is being written on a daily basis, as form of "resistance to the thinning of the world" [5].

Conclusion

The institutional and financial framework being developed in public cultural policies is helping to support and accompany artistic creation projects at different territorial levels, public/private partnerships and contributions from non-institutional players (foundations, civil society). This process has the potential to involve local populations and users in the direction of cultural policies. Ensuring that forward-looking landscapes are taken into account in regional development projects on a long-term basis, and disseminating this information to local residents, is part of a process of awareness-raising and transparency that is developing in response to the strong demand for exemplary public action. In this respect, local authorities have the capacity to generate changes in practices by generalising and widely disseminating exemplary approaches within the population, particularly in terms of spatial planning [11].

The relationship with time structures our operational stance to the arts-sciences-society approach around the transdisciplinary of the issue of Sustainable Living in the Anthropocene era. The 21st century, marked by the effects of global change, calls for the deconstruction of corporatism through the pooling of multidisciplinary viewpoints. The formulation of controversies brings together the dynamics of action and encourages the mobilisation of citizens around the common challenges of the Earth's habitability [8]. Fighting against the acceleration of time [13] is necessary here to build common narratives, share methods and harmonise objectives in an "ecology of practices" [15] towards the composition of shared and "actionable" knowledge [1].

The artistic approach and aesthetic emotion possess this capacity for slowing down, a source of complicity between individuals and between generations. Through the postures of the clown and the aerial circus artists, we identify dreams and laughter as a means of decentring, of extricating ourselves from the present, from a functional and sometimes sombre immediacy, so that we can project ourselves fearlessly into the future. Aesthetic emotion can become a powerful political lever, provided that artistic aesthetics is placed alongside other aesthetics, political and scientific [9]. Political and committed art thus represents a potential for sensitive citizen mobilisation based on the immaterial, capable of opposing the model of the accumulation of wealth and personal enrichment.

When local residents take up issues of social and environmental justice, they make them a priority for public and civic action. These issues mobilise and unite citizens who want to take action and make their voices heard by public authorities. Relaying this post-modern narrative in favour of the Common Good is neither dangerous nor surreal, unlike keeping it quiet. It is a political choice in the sense that it expresses a vision of the world and a proposal for the future of people who share common conditions of existence.

Acknowledgements

The author would like to thank *Sète Agglopôle Méditerranée* and its Director of Heritage and Archaeology Laurent Fabre. We would also like to thank all the members of the MangeNuage company for their involvement in the "*Messagers du littoral*" project. Thanks to Richard Béziat for the illustration of Figure 4, and to all the reviewers, whose constructive comments contributed to the quality of this article.

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ASSESSING BEACH ATTENDANCE AND PRACTICES IN A LARGE COASTAL CITY. A CASE STUDY IN MARSEILLE (FRANCE)

Samuel Robert, Marie-Laure Trémélo

Abstract: In large coastal cities, beaches are very important public open spaces. However, except in a few studies investigating interactions between uses and environmental beach quality, beach attendance and practices are generally poorly studied. In this context, this paper deals with a research initiative developed in Marseille (France), in order to: 1) assess beach attendance in summertime, 2) survey users' practices, habits and preferences, and 3) interview municipal beach managers. Between 2016 and 2020, we collected data from 8 am to 8 pm on several summer days, following different time frames (three consecutive days, a full week, and the same weekday in July). We operated in three different beaches, one being studied every year. Attendance was assessed hourly, and practices were evaluated through face to face questionnaires on the field. The results obtained present interesting findings on several aspects. They help to better understand beach attendance as a system within the city at various time scales and throughout different geographical locations. They also help providing guidelines to set up a more ambitious and complete system to monitor beach attendance and practices.

Keywords: Beach attendance; Beach practices; Assessment; Large city; Marseille

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Samuel Robert, Marie-Laure Trémélo, *Assessing beach attendance and practices in a large coastal city. A case study in Marseille (France)*, pp. 496-507, DOI: 10.36253/979-12-215-0556-6.45

Introduction

In large coastal towns, beaches are of great social importance. They are places for leisure, sport activities and socialising, visited all year round. They provide an opportunity for bathing and contact with the sea, in a sometimes oppressive urban environment that grounds a desire for open spaces. They are an integral part of local culture and contribute to the image of the city. They must therefore fall under public management and policy that is both appropriate to users' expectations and in line with the more general social and ecological issues facing coastal areas today: erosion and sediment depletion [4], environmental pressures [1].

Developing a beach management policy requires data on visitor numbers and user practices [10]. Beach attendance and its variation over time is essential data [2]. For example, it can be used to calibrate cleaning operations, bathing surveillance, public transport services to beaches, and to assess improvements to be made in these fields. It is also necessary to know what users do and how they feel, in order to understand how beaches are used and frequented, to anticipate any problems, to run prevention or communication campaigns and, more generally, to ensure that management evolves in line with users' practices and aspirations. However, such data is rare for beaches in large cities [3]. Until today, this area has not much attracted the attention of local public authorities, who are more concerned with monitoring bathing water quality or struggling erosion. Unlike some seaside resorts, for which this information is more frequent because it is part of the monitoring of their economic performance, few large coastal towns have figures for the number of people visiting their beaches or studies that provide information on the practices, expectations and perceptions of beach users. Given the ecological and social challenges that authorities are currently facing and will continue to face in the future, this is a gap that needs to be filled. How will large cities continue to offer beach areas to all in the context of the climate change and its effects considering beach erosion on the one hand and increasing heat waves, urban heat island on the other?

In this context, we report on an initiative we developed in Marseille (France), with a multidisciplinary observatory dedicated to the study of coastal environment. From 2016 to 2020, we carried out a study on some of the city's beaches to: characterize beach attendance, user practices and preferences, in relation to management methods; understand the functional integration of the beaches into the city; and enable local authorities to take a critical look at their actions.

Materials and Methods

The work was carried out within the framework of the Observatoire Hommes-Milieux Littoral méditerranéen (OHM-LM), set up in 2012 by the French CNRS, of which Marseille is one of the four study sites. The aim of OHM-LM is to observe and analyse social and ecological dynamics within the coastal zone by promoting interdisciplinary works and connections between scientific and local players. It studies the effects of integrated coastal zone management principles on the urban and recreational pressures that have been exerted on the Mediterranean coast for several decades, while taking into account contextual phenomena such as climate change, loss of biodiversity and globalisation. To this end, four specific coastal objects are targeted for study: beaches, ports, lagoons and coastal protected areas.

Study area

In France, Marseille is a large municipality (240 km²) with a coastline divided into three main sections: a harbour front in the north; an urban and seaside front in the centre-south; and a natural front, part of the Calanques National Park in the far south, to which must be added two archipelagos (figure 1). In 2020, the population is around 870 000 inhab., making it the most populated municipality in a metropolitan area of 1.9 million. Undergoing a transformation of its socio-economic base, the city is attracting more and more tourism and tertiary activities, while the port is in decline with most activities now located in Fos-sur-Mer, some 50 km away.

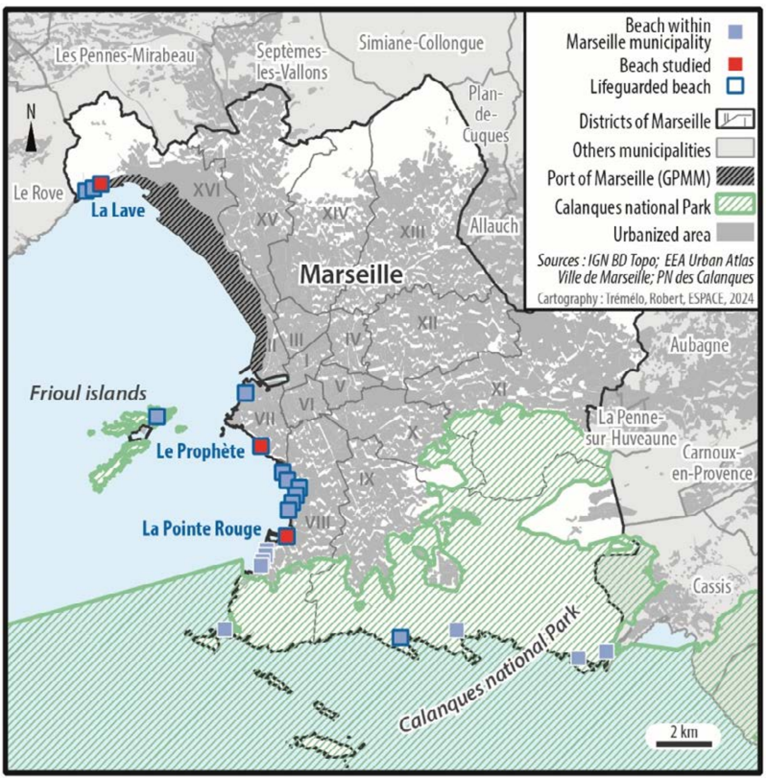

Figure 1 – Location of the 21 beaches of Marseille.

The coastline includes natural pocket beaches and, above all, artificial beaches reclaimed from the sea in the 1980s (Prado beach park and Corbière beach park). Pocket beaches and the beaches of Corbière are sandy, whereas those of the Prado beach park are made of mixed materials: sand (0.2 to 0.4 mm in diameter), gravel or 'rice grain' (3 to 8 mm in diameter) and pebbles (between 20 and 60 mm in diameter). With the exception of the Corbière beach park at the northern end of the territory, beyond the port area, Marseille beaches are all located in the southern half of the city. The total surface area of these beaches is 90,000 m², divided between 21 beaches, 15 of which are managed specifically for the summer season. This runs from 1st June to 31st August, a period of 3 months during which the city's services provide bathing surveillance, public showers, toilets, free lockers, daily monitoring of bathing water quality and, of course, cleaning and rubbish collection. At the end of the season, the service responsible for bathing surveillance provides an overall estimate of the number of people using the beaches, which generally fluctuates around 2 million people, without being more precise.

In the municipal organisation chart, beach management comes under the responsibility of the Department of the Sea. Its political referent is an elected representative who is a deputy mayor of the city, in charge of '*marine biodiversity, the management, preservation and development of coastal and island marine areas, beaches and seaside facilities, water sports, sailing and diving, and the development of the tradition of the sea and the open sea'*. Beaches are therefore part of a broad public policy for the coast and the sea. After a ten-year 'Beach Plan' launched in 2011, which has helped to upgrade certain beaches (demolition of hard-standing facilities built on the public maritime domain, improved access, etc.), beaches are now being considered in a more global approach, which requires a clear understanding of who uses them, for what purposes and how.

Measuring beach attendance

Assessing the number of beach-goers was carried out on an exploratory basis, as it was not possible to finance a study covering all the city's beaches at any time of the day or year. The focus was therefore on the summer period and on a few representative beaches along the Marseille coastline.

A protocol for counting users was first developed and tested at various sites. It is based on two distinct operations. One consists of counting the number of persons entering and leaving the beach by time slot, which is possible on beaches that are accessible by a compulsory passageway. The other is based on photographic images taken hourly, on which users are then counted using photo-interpretation in the laboratory [7], [8], [9]. The first one allows an accurate assessment of the total number of people present on the site during the day and its variation from one hour to the next. The second one provides a slightly poorer assessment (the number of people on the beach is underestimated, because of masks on the images), but it does allow the number of users in the water to be counted with accuracy.

This protocol was applied to a beach chosen as the reference site for the study: Le Prophète beach (figure 1). Data was collected between 2016 and 2020, i.e. five successive summers, each time for a few days in July. Counts were made between 8 am and 8 pm and photos were taken at 8 am, 9 am, 10 am, and so on until 8 pm, in order to track changes in visitor numbers over a whole day, and to study the variation in numbers over different time span: several days in a row, and from one year to the next at the same day (table 1). In 2017, two other beaches were also observed simultaneously with Le Prophète beach for three days of the same week: Lave beach, part of the Corbière beach park to the north, and Pointe Rouge beach to the south.

Table 1 – Field work days (data collection for visitor numbers and practices).

Beach	2016	2017	2018	2019	2020
Prophète	3 days 18, 19 and 20 July	7 days 10 to16 July	1 day 18 July	1 day 17 July	1 day 15 July
Lave		3 days 11, 13 and 15 July			
Pointe-Rouge		3 days 11, 13 and 15 July			

Collecting data on beach goers' practices

In parallel with the evaluation of visitor numbers, a questionnaire was administered to find out who goes to the beach, how and why. Divided into five sections (table 2), it was designed to allow relevant themes to be monitored from one year to the next and to incorporate specific topics in certain years, depending on the opportunities for interdisciplinary research within OHM-LM. For example, Section 2 included questions on sea water quality, the use of toilets and showers facilities in 2016, 2017 and 2018 [11], sunscreen use in 2017 [5], and the return to the beach after the 1st Covid-19 lock-down in 2020 [6].

Table 2 – Questionnaire sections and topics.

Sections	Topics
1- Your relationship with the beach	Frequency of visits; preferred time to come; time spent on site; means of transport used; motivation for coming on the day in question; habit of visiting other beaches
2- Your activities and practices	Usual location on the beach; usual activities; bathing practices; use of sanitary facilities; look at the weather forecast before coming; look at the water quality data sheet; use of sun cream (in 2017); return to the beach after Covid-19 (in 2020)
3- Your perception of the place	Personal assessment of the quality of the beach; Personal assessment of the attendance; Personal assessment of the bathing water quality; Wishes for change in 10 years' time
4- Socio-demographic profile	Gender; Age; Status (resident, tourist, visitor); Place of residence; Professional activity; Accompanying persons
5- Context of the interview	State of the sky when questioning; colour of the beach flag; special remarks

In practical terms, the questionnaire was administered face-to-face by specially trained interviewers, who used paper printed questionnaires. Each day, the survey was announced on the beach by microphone and by a poster displayed next to the lifeguards' booth. Also, interviewers were identifiable thanks to name tags with the logo of the OHM-LM. The sampling strategy consisted of reaching the widest possible range of people present on site, while taking care to maintain a balance in terms of gender, age groups, and number of persons questioned per hour. The aim was not to be statically representative of regular beach goers, who are a population whose socio-demographic make-up is unknown, nor to be representative of the population of the town or adjacent neighbourhood. Beach users were questioned on site from 8:00 am until 8:00 pm and, for each of them, the survey lasted about 15 minutes. During this five-year study, nearly 700 people were surveyed following the same protocol.

Results

The amount and diversity of data produced cannot all be presented here. We will restrict ourselves to mentioning the main lessons that can be drawn from it, while referring to other resources that have already been published.

Beach attendance

Over the observation period, the number of people coming to Le Prophète beach is irregular, but always much higher than the official data from the Health services (1300 users a day as per the beach profile). In 2016 (3 days of counting), the average number of users is 3470 per day. In 2017 (7 days), it is 3060. Subsequently, they are 5514 on 18/07/2018, 2,089 on 17/07/2019 and 1631 on 15/07/2020. There are several reasons for these variations in visitor numbers. First, they vary from day to day, depending on the weather and occasional bathing bans because of bad water quality (like on 15/07/2020). Second, visitor numbers are higher after 14 July, which marks the start of the peak tourist season in France. They are also higher at weekends than during week days and on Wednesdays than on other days of the week. In addition to these general explanations, we noticed that a change in the accessibility to the beach impacted attendance rather seriously after 2018. Before, our counting never fell below 2500 visitors per day. In that period, it was possible to park on the street serving the beach, straddling the pavement on the sea-side. In spring 2019, the street was upgraded to accommodate a cycle lane and one lane of car traffic was lost, making impossible parking on the seaward side. This resulted in a drop in visitor numbers, as reflected on Wednesday 18/07/2019, a sunny day when bathing was not forbidden, and confirmed on Wednesday 17/07/2020, when it was accentuated by the closure of the bathing area from 11 am. In other words, the findings of our assessment are twofold: beach attendance at Le Prophète is underestimated by the authorities, and visitor numbers have fallen as a result of fewer parking facilities nearby.

Besides the drop in the attendance, the hourly count of users shows that daily visitor numbers vary following a bimodal pattern that persists over the observation period. In general, the number of people rises until it reaches an initial peak in the late morning (11 am), then falls back slightly until 2 pm, before rising again to reach a main peak at around 5 pm (figure 2). This is a familiar pattern, already observed elsewhere thanks to other studies [2], [10].

However, deviations from the bimodal model are frequent, depending on weather conditions, festive events in the city, or the closure of bathing areas due to accidental pollution. Results also show that, on the same day, the model may not apply to all the city's beaches. In 2017, the counts carried out simultaneously at Le Prophète, La Lave and Pointe-Rouge showed that the number of users did not vary in the same way, particularly at La Lave (figure 3).

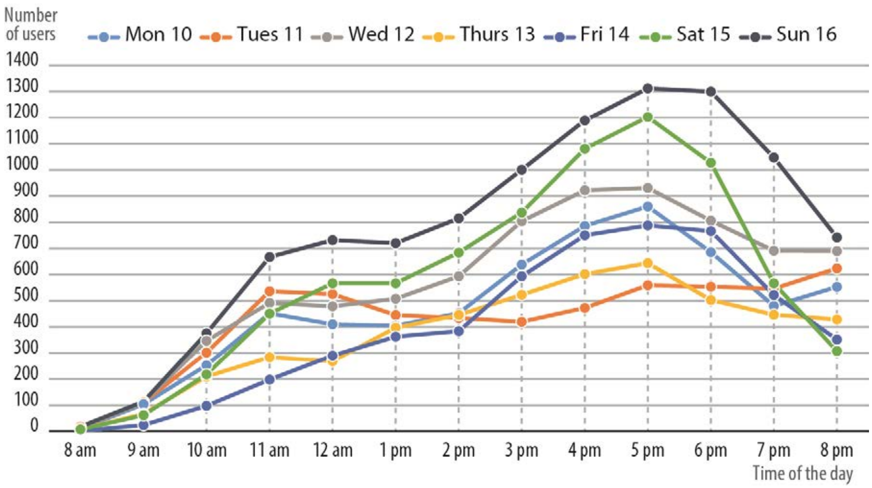

Figure 2 – Beach attendance at Prophète beach between 10 July and 16 July, 2016.

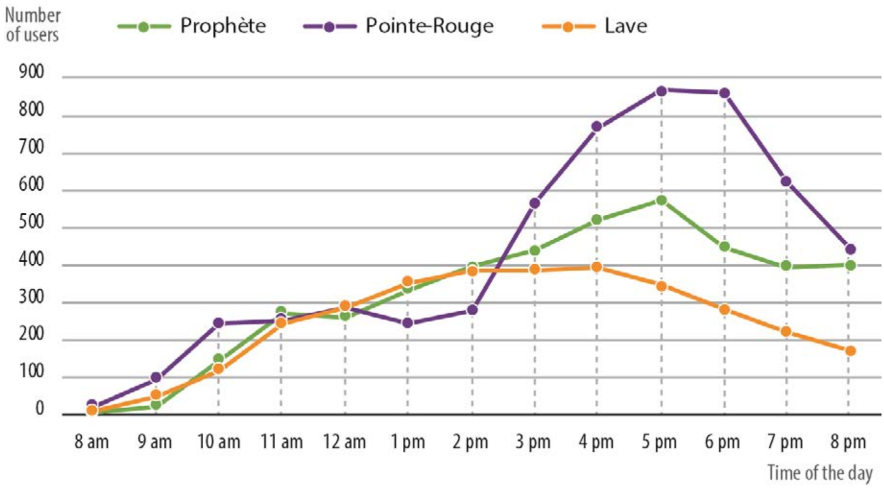

Figure 3 – Beach attendance at Prophète, Lave and Pointe Rouge beaches on 13 July, 2017.

Practices

A large proportion of beach users are residents of Marseille (table 3). They most often live near the beach surveyed, where they say they are "regulars" and where they mainly go in the company of other people and by car. Although the peak is in the afternoon, they say they prefer to come in the morning. Most often, the time they spend at the beach rarely exceeds half a day.

Table 3 – A few data on beach goers' profile and practices (questionnaire 2017).

	Resident %	Regular %	Accompanied %	Come by car %	Half a day %
Prophète	71	60	73	49	29
Lave	87	73	76	74	48
Pointe-Rouge	58	51	78	57	33

If they are used to come to the beach where they were interviewed, users like to go to other beaches in the city, in particular the large beaches of the Prado beach park (figure 4). However, the Corbières beach park, in the more working-class northern districts, is less attractive.

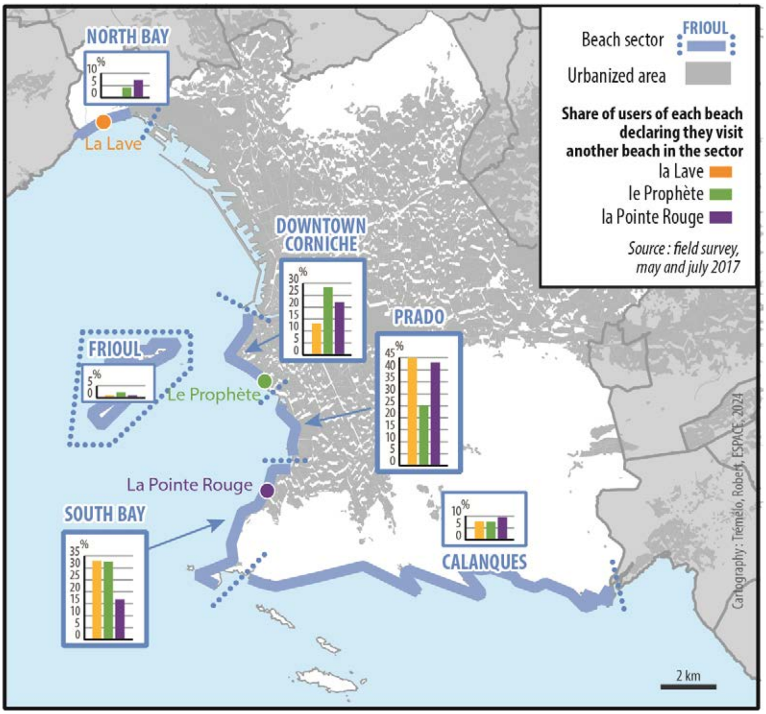

Figure 4 – Other beaches of Marseille where beach goers also go (by geographic sectors).

Outside Marseille, the other beaches most visited are located in a relative vicinity, outlining a distance effect: La Lave users tend to visit beaches in neighbouring communes to the north. Pointe-Rouge users tend to go to beaches in neighbouring communes to the south (figure 5).

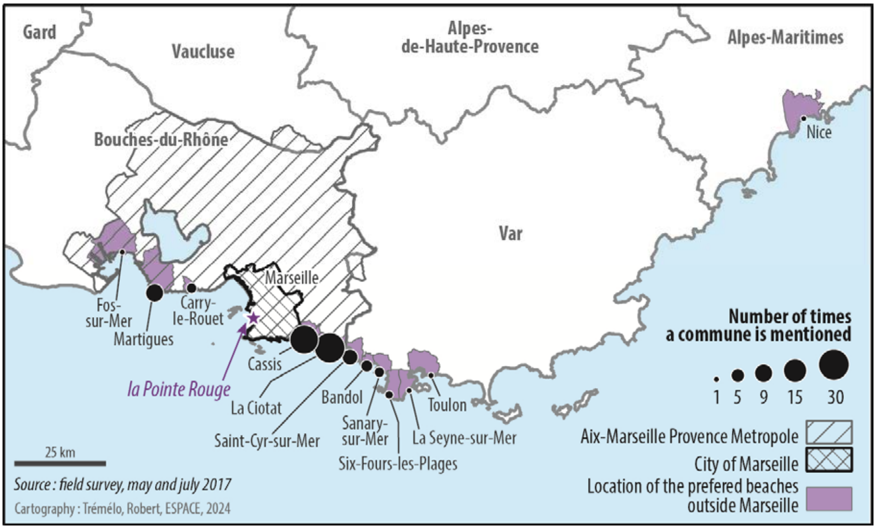

Figure 5 – Beaches outside Marseille attended by users interviewed at Pointe Rouge beach.

The vast majority of users say they go swimming every time they come to the beach, and half of them prefer to stay close to the water. Water quality is very important to them (between 87 % and 93 % of respondents), but very few consult the sheets displaying the water quality measurements from health services. They are also very sensitive to the quality of the beach itself, but curiously relatively few use the public toilets (around half of respondents).

Representations

Overall, users like the beach they use to go (figure 6). They highlight its "pleasant" (agréable, in French), "family" (familial) and "friendly" (convivialité, sympathique) nature. Above all, they see it as a place where people can socialise, pleasant and even attractive. However, depending on the location, they also point to negative aspects that could be improved. Cleanliness, for example, is frequently mentioned at Le Prophète, less at Pointe-Rouge and La Lave. Too much attendance was mentioned at La Lave and Pointe-Rouge, but not at Le Prophète. When asked how they would like to see these beaches evolve in the future, respondents tend to favour maintaining the current situation ("that nothing changes, that everything stays as it is"), apart from improving cleanliness. They are attached to the public character of the beach and its socially mixed attendance.

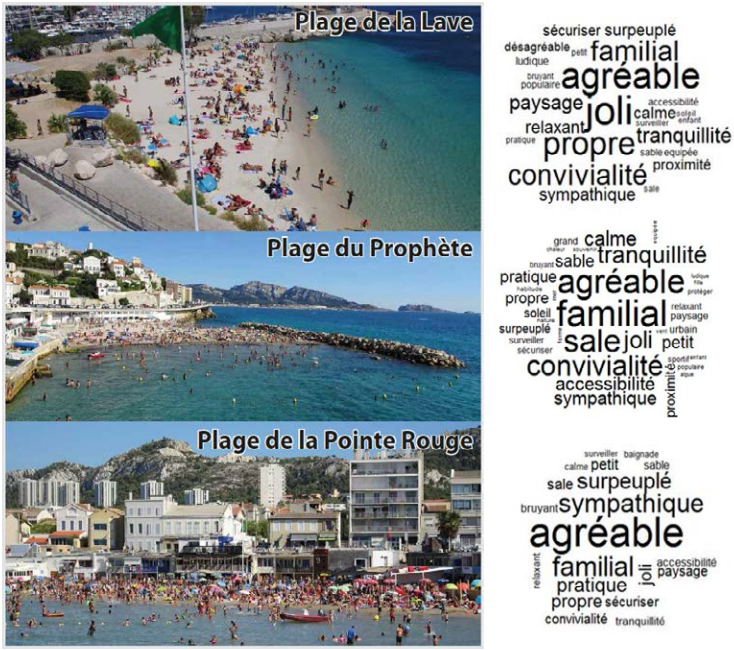

Figure 6 – The three words most often used to describe beaches

Discussion

The approach developed on the beaches of Marseille provides an insight into the system of beach use in a large city. However, there are still shortcomings and new developments should be encouraged.

Extend to other beaches and other times of the year

While the data produced is instructive, it remains insufficient for a number of reasons. Firstly, given the great diversity of the city's beaches, it would be necessary to study other sites, in particular the large beaches of the Prado beach park, which are very popular and conducive to outdoor sporting activities, and the pocket beaches to the south of Pointe-Rouge, which are very popular with young adults but also very impacted by erosion. Observations and counts should also be carried out outside the summer season, particularly in the spring and after the summer when, on fine days, beaches sometimes receive very high numbers of visitors. Similarly, it would be interesting to look at the number of people in the evenings and during the early part of the night, which is relatively high during the summer period and about which nothing is known. Finally, with a view to gaining an overall understanding of the beach visitor system, it would also be advisable to explore the possibilities of automated counting. Although various attempts have been made in the recent past, the municipality has never shown much willingness to go down this route and the experiments have proved rather pitiful.

Data appropriation by managing authorities

Today, one of the challenges of this initiative is its appropriation by the management authorities. Developed under the terms of an agreement, the research team's work has been accompanied and partly financially supported by the Department of the Sea. Presentations and discussions took place both at the design and at the feedback stages, and the data produced has all been made available, as has the published work. However, capitalisation of the knowledge acquired is questionable. There was a failure to pass on the information produced when there was a change of contact person following a turnover within the institution, at both political and technical levels. It is also difficult to grasp how the city takes advantage of the knowledge produced, both in its daily actions and in the design of its coastal management policy for the benefit of residents. Recent discussions with the have highlighted these difficulties and identified a new area for collaboration. This would involve organising workshops between researchers and local authority staff to work on the operational use of the data produced, on the one hand, and to identify new areas for research and development, on the other.

Studying beach use from inside the city

In terms of research, and more particularly to understand how beaches fit into the socio-ecosystem of such a large coastal city, the study of beach use and practices would require complementary or even alternative approaches. In addition to looking at the beach itself, it would be interesting to explore the use of the beach from the city. The aim would be to assess how often and how easy or difficult it is to get to the beach from different parts of the city. This could also lead to the search for privileged relationships between neighbourhoods and beaches, which would not simply be a question of spatial proximity. From the perspective of an inclusive city, where the sea can be seen as a common, the question of who goes to the beach versus who doesn't remains wide open. This raises questions about how people access the coastline by public transport, how they see the coastline and beaches, and the different forms of attachment they have to places.

Conclusion

Assessing beach use and describing beach practices in a large city is a huge undertaking. It requires a considerable collection of data, which is not easy to organise. The approach undertaken in Marseille, exploratory in its design, has made it possible to acquire some basic knowledge and to characterise certain aspects of the relationship between users and the beach. It is also likely to lead to the development of a roadmap for a more comprehensive and ambitious observation of the beach attendance system in this city, provided that the authorities in charge of the beaches agree to support it.

Acknowledgements

This work was supported by Labex DRIIHM (ANR-11-LABX-0010) funded by the French Government’s Investissements d’Avenir Program, through OHM

Littoral Méditerranéen. It was also supported by the City council of Marseille through an annual subvention (N◦ DCM 20/0510/UAGP).

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MONITORING THE TRANSFORMATIONS OF URBAN AND NATURAL LANDSCAPE IN MEDITERRANEAN CITIES BY PROMOTING LANDSCAPE SETTING ARCHETYPES

Ana Sopina, Bojana Bojanić Obad Šćitaroci

Abstract: The research phenomenon of the 'urban and natural landscape relation' as the landscape setting of cities testifies to 25 centuries of urban culture in the Mediterranean. The holistic understanding of the landscape relation as a multidimensional changeability process presents a challenge for its application in spatial planning. The research hypothesis introduces landscape archetypes as a conceptualisation principle for developing an interdisciplinary and comprehensive approach to landscape.

The review of landscape dimensions and the three natures theory is used to set spatial planning, collective psychology, and art photography as the main research fields for establishing the landscape setting and landscape transformation archetypes. These landscape archetypes are verified by comparing the Mediterranean cases of Livorno, Ancona, and Dubrovnik.

Landscape archetypes aid in dealing with the complex nature of landscape relations by acknowledging the values found in each landscape. Spatial planning, collective psychology, and art photography contribute to raising collective and individual landscape consciousness and foster a holistic approach to monitoring landscape transformations.

Keywords: spatial planning, collective psychology, art photography, Tyrrhenian Sea, Adriatic Sea

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Ana Sopina, Bojana Bojanić Obad Šćitaroci, *Monitoring Transformations of Urban and Natural Landscape in Mediterranean Cities by Promoting Landscape Setting Archetypes*, pp. 508-519, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.46

Introduction

The research phenomenon of the 'urban and natural landscape relation', which is identified as the landscape setting of cities, testifies to 25 centuries of urban culture in the Mediterranean. It is a multidimensional changeability process that integrates the spatial, temporal, and perceptive character, as well as functional and holistic principles fostered by the spatial planning point of view (Sopina, 2024). The phenomenon of the landscape relation is a layer of the *Urbanscape Emanation* concept (Obad Šćitaroci and Bojanić Obad Šćitaroci, 2019), understood as the impact of the city system on its landscape. The research[1] premise considers spatial planning of landscape transformations as a necessary tool (Council of Europe, 2006) in making natural and urban conditions more holistic, resilient, and sustainable.

Determining the landscape relation as a multidimensional phenomenon and a changeability process implies the need to involve various scientific and art disciplines. Establishing the need for a comprehensive approach to landscape presents a challenge for its application to spatial planning, which raises the research questions - How to address the complex phenomenon and process of the landscape relation in an interdisciplinary (scientific and artistic) manner? How to overlap different approaches to landscape settings for spatial planning enhancement?

A comprehensive conceptualisation of landscape (Council of Europe 2000, 2008) defies precise definition, categorisation, and delineation. The nature of landscape exists equally in reality (physical) and representation (metaphysical dimension) (Pedroli and Van Mansvelt, 2002; Azzena, 2011; Taylor, 2012), which raises awareness of various landscape values (and encourages different levels of landscape consciousness). The hypothesis introduces landscape archetypes (Cullum et al., 2016) as an approach that moves between various fields of research, theoretical frameworks, empirical observations, collective perceptions, and classification rules upon which landscape research, management plans, and art are based. Landscape archetypes are used as conceptualisation principles that embody the (metaphysical) representation of landscape within (the reality of) the physical world with constant landscape change. The research objectives are: (i) to determine the research fields that unite the reality, representation, and changeability of the landscape relation to be addressed in spatial planning and (ii) to establish landscape setting archetypes for monitoring the transformations of urban and natural landscape.

A research approach that integrates scientific methods of literature review, field research, and case study comparison is applied by identifying landscape archetypes that enhance spatial planning. The expected scientific contributions promote landscape archetypes in dealing with the complex natures of the landscape relation and in monitoring transformations of urban and natural landscape.

[1] The research is carried out as a part of the postdoctoral research on *The (Peri)Urban and Natural Landscape Relation of the Mediterranean*, which is a part of the *Urbanscape Emanation* research project, conducted at the University of Zagreb, Faculty of Architecture, led by prof. Bojana Bojanić Obad Šćitaroci, PhD until 2023 and by asst. prof. Tamara Zaninović since 2023.

Methods and materials

The research approach is based upon the literature review method in order to set the main taxonomy and determine the main research fields that foster a holistic approach to spatial planning. Conceptualisation and synthesis of the main research fields in the review of landscape dimensions and the three natures theory are used to identify the landscape archetypes that enhance spatial planning practices.

These theory-based landscape archetypes are verified within the Mediterranean cases of Livorno, Ancona, and Dubrovnik, representing the intensive encounter of urban and natural landscape on the East Tyrrhenian, West Adriatic, and East Adriatic Coast. The three case cities are compared by the four natures of landscape transformation that integrate landscape dimensions and the three natures theory.

Figure 1 – Historical illustrations (up) and contemporary photographs (down) as the representation of the urban and natural landscape relation of Livorno (left), Ancona (center), and Dubrovnik (right). Source of historical illustrations: Livorno[2], Ancona[3], Dubrovnik[4]. Author of photographs: A. Sopina, 2019 – 2024.

Theoretical framework

Setting the main taxonomy of the research establishes an absolute view of landscape as a holistic approach that explicitly addresses the subjective landscape (soul) by taking the inter-subjective landscape (mind) and the objective landscape (body) as starting points (Pedroli and Van Mansvelt, 2002). Thus, landscape expresses and reflects relations that drive the ongoing process of place-making where change is an essential property of landscape dynamics (Azzena, 2011) and landscape transformations. The landscape setting of a city, town, or settlement is

[2] https://www.ribapix.com/View-of-Livorno_RIBA16555

[3] https://www.gettyimages.com/detail/illustration/historical-view-of-ancona-italy-wood-royalty-free-illustration/1219161358

[4] http://arhinet.arhiv.hr/_DigitalniArhiv/GrafikeHrvatskihMjesta/DubrovnikPogledIstok.htm

determined by the mutual influence, transformation, and co-development that form the (inter)relation between urban and natural landscape. This inter(relation) connects spatial, perception, and identity constituents with a specific landscape setting (Sopina, 2024) - urban location and its natural landscape. Landscape archetypes involve constant and recurring models and symbols of landscape - abstract exemplars of groups, classes, landscape types, and values.

Landscape setting archetypes

The spatial, perception, and identity constituents of the landscape setting originate from the spatial, societal, and symbolic landscape dimensions. These threefold landscape dimensions are identified in various research approaches focused on perceiving landscape identity (Relph, 1976; Montgomery, 1998; Parris, 2002; Lucas, 2009; Bell, 2002) and spatial relations (Guattari, 1989; Foucault, 1980; Lefebvre, 1991; Soja, 1996) (Table 1).

Table 1 – Dimensions of the urban and natural landscape relation. Based on Sopina, 2024.

Identity of place (Relph, 1976)	Physical features and appearance	Activities and functions	Meanings and symbols
Sense of place (Montgomery, 1998)	Physical form	Activity	Meaning
Visual perception of landscape (Parris, 2002)	Structure	Function	Value
Criteria for the assessment of heritage landscape (Lucas, 2009)	Visual experience	Existential experience	Spiritual experience
Landscape patterns (Bell, 2002)	Ecological patterns	Patterns of human use	Aesthetics of nature
Three ecologies (Guattari, 1989)	Environmental ecology – material environment	Social ecology – social environment	Mental ecology – human subjectivity
Spatial discourse (Foucault, 1980)	Space	Power	Knowledge
Trialectics of social space (Lefebvre, 1991)	Perceived space	Lived space	Conceived space
Thirdspace (Soja, 1996)	Spirituality Physical space	Sociality Social space	Historicity Mental space
Dimensions as setting of the urban and natural landscape relation	**Spatial dimension**	**Societal dimension**	**Symbolic dimension**

Just as the goal of an individual is to achieve a sense of cohesive self, thus the aim of a holistic approach to planning the urban and natural landscape relation is to simultaneously involve the spatial, social, and symbolic landscape dimensions (Figure 2). This is achieved by complementing the spatial planning field (Sopina, 2024) with collective psychology (Jung, 1959) and art photography (Wells, 2011) in order to establish landscape archetypes that integrate landscape representation and reality with landscape change. What confirms the spatial, societal, and symbolic landscape dimensions (Table 1) as the landscape setting archetypes is that the three dimensions can be represented and applied in various research fields as well as in their levels (Figure 2).

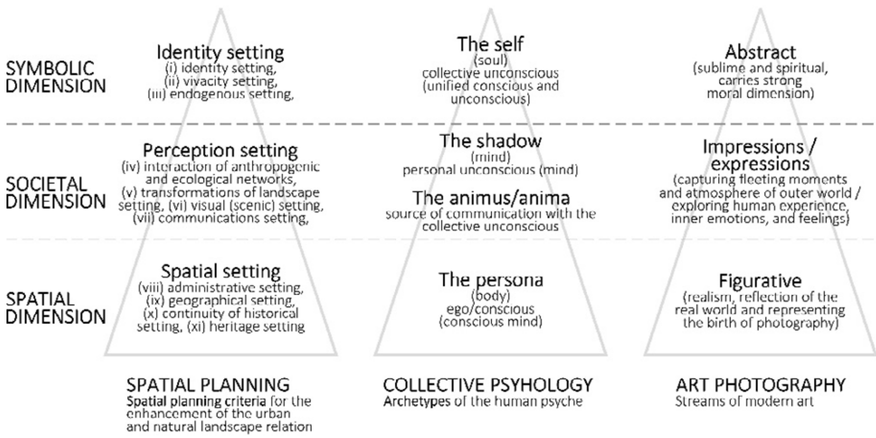


Figure 2 – Integration of (spatial) planning, (collective) psychology, and art (photography) in achieving a holistic approach to the urban and natural landscape relation.

Landscape transformation archetypes

Landscape transformations involve and intertwine urban development with the evolution of natural landscape. Inherited values of landscape continuity and constant landscape transformations are embodied in the natures of landscape where nature is understood as the essence of landscape that is equally applicable to the urban, coastal, and mountain landscape of the Mediterranean cases.

The Three natures theory by Cicero (2008) was updated by Hunt (2000), expanded by inherent aspects of all the phenomena (Garfield, 2002) that evoke the integrity of landscape setting/dimensions, and translated to the landscape scope by the typology of cultural landscape (UNESCO WHC, 2023). The interpreted natures of the primeval, transformed, and planned landscape are complemented with the fourth nature of the deprived landscape recognised as Terrain Vague (de Solà-Morales Rubió, 1995). This fourth nature is identified in spaces that have lost their identity, but where nature emerges spontaneously as new wilderness (Kowarik, 2005, 2013), wild city (Metta and Olivetti, 2020), hybrid natures (Metta, 2022), and novel ecosystems (Hobbs et al., 2006) facilitating dynamic ecosystems and social uses (Bakshi and Galagher, 2020).

What confirms the types of landscape natures as the archetypes of landscape change (Table 2) is that the archetypes of pristine, transformed, designed, and deprived landscape reveal the stages of landscape transformation that can be applied to various types of landscape – equally to natural, cultural, mountain, urban, and other landscape. In this manner, the values found in various types of landscape can be equally perceived, read, and respected.

Table 2 – Landscape transformation archetypes and landscape natures present the constant change of the urban and natural landscape relation. Based on Sopina, 2024.

Three natures (Cicero, 2008)	First nature (wilderness)	Second nature (agriculture)	Third nature (landscaping)	/
Three natures (Hunt, 2000)	First nature (wilderness)	Second nature (countryside)	Third nature (gardens)	/
Vasubandhu's Treatise on the Three Natures (Garfield, 2002)	Imaginary nature is non-existent emptiness	The dependent nature is the existent emptiness	The perfect nature is the ultimate emptiness	/
Cultural scape (UNESCO WHC, 2023)	Associative cultural landscape	Organically evolved landscape	Intentionally men-created landscape	/
Terrain vague (de Solà-Morales Rubió, 1995)	/	/	/	Terrain vague, landscape identity loss
Landscape transformation archetypes	**Pristine nature** of the primeval natural landscape	**Transformed nature** of the cultural landscape	**Designed nature** of the planned landscape	**New nature** of the degraded landscape

Verification of landscape archetypes in Mediterranean case cities

The Mediterranean case cities are compared by landscape transformation archetypes of the primeval, transformed, planned, and deprived nature, where each of the natures is presented by the matrix of landscape photographs of the coastal, urban, and mountain setting (Photographs tables 1, 2, and 3). In this manner, each case city is presented by photographs of the urban and natural landscape relation that also carry archetypes of the spatial, societal, and symbolic landscape setting.

(Second) Transformed and evolved nature of landscape heritage

The organically evolved nature of landscape is presented by the cultural landscape that is transformed over a period of time in harmony with nature where (most of) human interventions acknowledge and emerge in line with the natural landscape. These are identified in the accessible coast of beaches, bathing sites, seaport coves, seacoast promenades, and coastal woods integrated into parks and gardens. Spontaneously developed neighbourhoods, traditional settlements, and manor houses of Livorno, Ancona, and Dubrovnik that have gained heritage value are examples of the organically evolved nature of the urban landscape. The cultivated landscape of agricultural fields, forests kept for wood, meadows maintained by livestock breeding, and the network of dwellings and infrastructure in mountains and hills represent the organically evolved natural landscape that is found in the hinterland. The approaches of adaptation, renewal, and/or revitalisation have to be applied to transformed and evolved areas to be developed as urban and natural landscape heritage.

Photographs table 1 – Landscape transformation archetypes as four natures (rows) of coastal, urban, and mountain landscape of Livorno. Photographs: A. Sopina, 2022 – 2024.

Coastal landscape	Urban landscape	Mountain landscape

(Third) Designed nature of the planned landscape

The designed and planned nature of landscape is both materialised in the planned urban landscape of cities and coastal infrastructure as well as in the designed natural landscape of parks and gardens. A built and developed coast of industry, ports, shipyards, and infrastructure (Livorno, Ancona, Rijeka), as well as an urban seafront and promenade (Livorno) represent the planned coastal landscape. A historicist centre of block matrix, residential neighbourhoods, industrial, commercial, and tourist zones, as well as designed public parks, cemeteries, and urban walkways represent the designed nature of the urban landscape. The planned nature is rare in the mountain landscape and identified in historical structures (Livorno) while in other cases it is mostly developed without respect for the setting and included in the (fourth) negated nature. The planned landscape that is already identified as heritage has to be protected by spatial planning, while other planned landscape has to be developed in a way to become landscape heritage.

Photographs table 2 – Landscape transformation archetypes as four natures (rows) of coastal, urban, and mountain landscape of Ancona. Photographs: A. Sopina, 2019 – 2024.

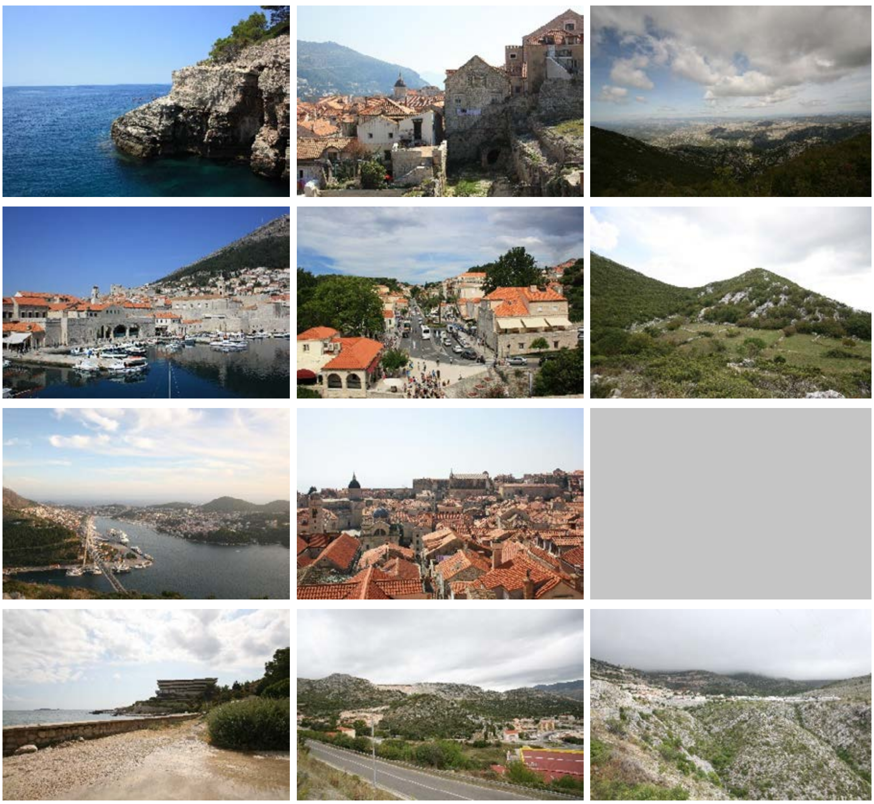
Coastal landscape	Urban landscape	Mountain landscape
		
		
		
		

(Fourth) New nature of the degraded and deprived landscape

The negated and deprived landscape includes both urban and natural spaces that have lost their inherent identity, urban landscape that lacks respect towards the natural setting, as well as natural landscape that has lost its values by human interventions. An abandoned and neglected industrial coast, inaccessible coast occupied by port infrastructure, infrastructure-burdened coastal landscape (road and train routes, parking, temporary trade), coast disconnected by train and road infrastructure, and sprawl of coastal settlement developed by secondary houses represent the deprived coastal landscape. The negated and deprived urban landscape is identified in the residential, commercial, and industrial sprawl occupying slopes, natural water flows, and agricultural land, scattered and informal settlements and suburbs developed by secondary housing, as well as in service- and parking-burdened public spaces. Landfills and quarries, unsuitable secondary housing, degraded woods, infrastructure-burdened and fire-devastated natural landscape represent the negated nature of mountain hinterland. These degraded and negated landscape are places for new nature, spontaneous wilderness, and ecosystems adapted to the anthropogenic setting. This needs to be addressed by spatial planning and focused in landscape design to integrate the aims of habitat restoration and societal use. The equilibrium between nature protection and urban development has to be achieved in order to equally raise the quality of the ecosystem and the quality of life.

Photographs table 3 – Landscape transformation archetypes as four natures (rows) of coastal, urban, and mountain landscape of Dubrovnik. Photographs: Sopina, 2014 – 2024.

Coastal landscape	Urban landscape	Mountain landscape



Contributions of landscape archetypes to strengthening spatial planning

The application of landscape transformation archetypes and landscape setting archetypes to case study cities verifies urbanscape and natural landscape as prime landscape archetypes. Urban and natural landscape as well as spatial, societal, and symbolic landscape dimensions and primeval, transformed, planned, and deprived natures of landscape exist only as an abstract conceptualisation because in landscape reality, representation, and change, each of them consists of the constituents of the other. A holistic approach to awareness, reading, and planning of the urban and natural landscape relation and the interventions in it introduces constitutional, transformation, and creative elements (Table 3) to be applied in scientific, professional, and educational fields of spatial and landscape planning.

Table 3 – Contributions of landscape transformation archetypes and landscape setting archetypes to strengthening spatial planning.

Natures of landscape **Landscape transformation archetypes**	First nature **Pristine / genuine landscape**	Second nature **Transformed / evolved landscape**	Third / forth nature **Planned landscape** **Deprived landscape**
Landscape setting archetypes Landscape dimensions	**Identity** Symbolic Intangible Metaphysical	**Perception** Societal Communal Collective	**Territory** Real Tangible Physical
Energy bodies of people	Soul/spirit	Mind	Physical body
Landscape scope	Landscape representation	Landscape change	Landscape reality
Temporal context of landscape research	Landscape past	Landscape present	Landscape future (landscape plan)
Stages of the spatial planning process	Re-evaluation stage Preparation stage	Decision stage	Intervention stage
Intervention types	Protection Activation	Adaptation Revitalisation	Introduction Addition
Identity maintenance	Highlighting existing identity	Restoring neglected identity	Bringing back lost identity
Stages of the design process	Context	Concept Idea	Realisation Expression
Landscape elements in spatial planning	**Constitutional** Landscape continuity	**Transformative** Landscape change	**Creative** Landscape planning/design

Identifying the origin, transformation, planning, and deprivation in both urban and natural landscape (Photographs tables 1, 2, 3) confirms that human development can contribute to the quality and diversity of natural landscape just as natural landscape contributes to the quality of cities and the quality of living. This can be achieved by identifying constitutional, transformative, and creative elements in spatial planning practices that respect landscape context and promote creative concepts and ideas for landscape realisations.

Conclusion

Landscape archetypes aid in dealing with the complex natures of the urban and natural landscape relation by acknowledging the values found (in different intensities) in all landscapes. The spatial (planning), art (photography), and (collective) psychology fields promote landscape quality and the quality of life, contribute to raising collective and individual landscape consciousness, and foster a holistic and resilient landscape approach for sustainable development. The variety of urban development and the natural landscape evolution as the landscape transformation archetypes (primeval, transformed, planned, and deprived natures of landscape) equally involve the landscape setting archetypes (spatial, societal, and symbolic landscape dimensions).

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SESSION

UNDERWATER AND COASTAL CULTURAL HERITAGE

Chairperson: Marinella Pasquinucci
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UNDERWATER AND COASTAL CULTURAL HERITAGE

This session examines issues related to the tangible and intangible cultural heritage of coastal areas and waterbeds. It covers a wide range of archaeological, historical, geographical, landscape topics, including the landscapes and their evolutionary dynamics, the settlements and settlement patterns, navigation in its various aspects, the transmission of goods, cultures and ideas, the structures of ports and landings, historic buildings and museum heritage, enhancement and protection, fishing traditions and fish processing activities, etc.

The papers published in this volume have been accepted by the Scientific committee of the Livorno 2024 Symposium for oral presentations or posters at the conference itself. They examine numerous Central Mediterranean coastal areas and one Sea of Marmara district, apply different highly topical approaches and cover a vast chronological range from prehistory to the present day. The authors work in institutions aimed at research, protection and enhancement of heritage.

The topics include archaeology, landscape and underwater archaeology, archaeological diagnostics and related documentation, architectural heritage, landscape protection, territorial planning, anthropological/identity studies, historical themes and local traditions, conservation and enhancement.

A few papers examine coastal stretches and the related sea beds (Aveta; Repola *et Al.*; Karadoller *et Al.*), conservation of ancient (Zicarello *et Al.*) and medieval/modern age buildings (Rescic *et Al.),* aspects of navigation (Benincasa *et Al.*). Other essays examine submerged and semi-submerged archaeological contexts in lagoon waters (Costa-Lucarini), specific coastal features, their recovery and enhancement (Comino-Lanza; D'Ecclesiis-Pellettieri). One paper applies the landscape archaeology methodology to the relationship between man and the environment in a territory rich in waters (Jaia-Ebanista).

Each of these contributions deserves attention from researchers and local authorities with various expertise. I point out a few details of the contributions, just to stimulate researchers and interested parties to read them in full.

In her paper *Coastal archaeological evidence in the Bay of Naples: vulnerability and directions for conservation and enhancement*, C. Aveta examines the areas bordering the gulfs of Naples and Pozzuoli, the islands of Procida, Ischia and Capri and their seabeds. This peculiar district is characterized by an exceptional wealth of archaeological evidence and by specific fragility and vulnerability. In fact, the area is exposed to damages caused by human activities and natural events, including the seismic activity and bradyseism that characterize the district.

According to the Author, the archaeological record should be considered as a document of the past and, above all, as a segment of local history to be reconnected in the territorial context, in the frame of active and integrated conservation and valorisation actions. Initiatives as the establishment of the Submerged Parks of

FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Laura Bonora, Marcantonio Catelani, Matteo De Vincenzi, Giorgio Matteucci (edited by), *Tenth International Symposium "Monitoring of Mediterranean Coastal Areas: Problems and Measurement Techniques". Livorno (Italy) 11th-13th June 2024*, © 2024 Author(s), CC BY-NC-SA 4.0, published by Firenze University Press, ISBN 979-12-215-0556-6, DOI 10.36253/979-12-215-0556-6

Baia and Gaiola are meritorious for the recognition of identity and historical-documentary values, but remain fragmentary. It is urgent to identify and implement a new policy aimed at creating a real network at national, regional and local level, which can achieve the protection, restoration, enhancement of the heritage and a full enjoyment by local communities, national and international visitors

In their paper *Archaeological markers below the lagoon waters*, E. Costa and C. Lucarini underline the peculiar characteristics of investigations in lagoon contexts. Surveying and studying submerged and semi-submerged archaeological contexts in lagoon waters can testify the impact of anthropogenic changes on the landscapes and allow the identification of significant archaeological markers relating to ongoing environmental changes. In particular, the lagoon of Venice is a very at-risk ecosystem, which needs to be monitored and protected from ecological, environmental and archaeological points of view. The applied methodology includes both traditional and digital up-to-date technologies (multibeam, topographic survey, photogrammetry, DEM, etc.) which provide a complete and comprehensive picture of the underwater sites, with significant advantages for interpreting, studying and monitoring the state of conservation/ degradation of the archaeological sites. The authors focus on a few relevant case studies in the Venice Lagoon and significant markers, e.g. the Relative Sea Level and construction techniques in Roman times.

L. Repola, V. Morra, J. Leidwanger, E. Greene and F. Sgroi present the paper *Coastal cultural landscapes: analysis and visualization of data.* Examining traditional tuna fishing in South-Eastern Sicily, they note that many of the related anthropogenic traces are still legible on the seabed, in close connection with the processing facilities on land. Therefore, they apply a new and strongly interdisciplinary approach to the study of the evidence related to the traditional "mattanza", supported by digital technologies for the production and management of information. The research methodology focuses on the analysis of spaces and on the phases and processes of use that have occurred over time. After an initial data acquisition steps consisting of three-dimensional digitization using laser scanners, LIDAR from UAS, terrestrial and underwater photogrammetry, the data are processed and segmented to support the subsequent geospatial analysis activities of the models both within modelling software and within a GIS platform.

An accurate representation of the coastal heritage, submerged elements and geomorphological characteristics of the area have been produced and studied, providing interaction matrices between the factors that make up the cultural context characteristic of this area of Sicily

The future lines of research include an expansion of underwater surveys for the production of an extended model of the seabed and the optimization of the information processing and analysis workflow.

In *The exploration of the coasts of Perinthos: what does the multibeam bathymetry survey tell us,* B. Karadoller, C. Imren and Z. K. Erdem present their research in *Perinthos* (Marmaraereglisi/Tekirdag/Turkey).

This ancient city is one of the most ancient and significant Thracian harbour settlements. In 46 AD the emperor Claudius made it the capital of the Thracian province. Thanks to its well-sheltered harbor, *Perinthos* was a base of the Roman fleet entrusted with the security of the *Propontis* (Marmara Sea). The functions and role of the city changed as Istanbul's importance grew.

From a historical-archaeological point of view, the district is a laboratory of great interest. A recent systematic multidisciplinary archaeological project initiated by the Ministry of Culture and Tourism involved both the ancient settlement and the adjacent seabed, applying marine and land-based multidisciplinary studies in a comprehensive approach.

Ground penetrating radar and magnetic methods were applied in specific areas identified through surveys. The remains of several buildings were identified. The offshore multi-beam bathymetry covered more than 1000 hectares and provided data of great interest, including a shipwreck of peculiar dimensions and features probably referable to the Roman inner port.

L. Comino and S. G. Lanza present the paper *The quarries in the coastal municipalities of western Liguria: reflections on landscape protection with a view to their recovery.* The study concerns areas characterized by radical transformations, due to industrialisation and urbanisation linked to seaside tourism, the railway and related infrastructures. Mining activities, and in particular open-cast quarries, have contributed to the transformation of the landscape, due to their strong impact on the morphological structure of the territory. They have played a strategic economic role in the national economy, e.g. for construction and infrastructure construction, but are no longer economically relevant or sustainable from an environmental and landscape point of view and therefore must be 'healed'.

This work examines some case studies and deepens the formation, evolution and decommissioning of quarries, focusing on the role that landscape protection can have in governing and directing operational choices in situations that are particularly delicate from a landscape, environmental and economic point of view.

A. M. Jaia and L. Ebanista present the paper *The Latium coast from Ostia to Circeo: settlement dynamics in a peculiar context.*

They examine the ancient settlement dynamics in a coastal stretch about 100 kilometres long, characterized by low sand dunes and lagoons which in ancient times occupied about half of the entire coast strip. The research is aimed at discussing the fundamental relationship between man and the environment in a territory dominated by rivers, ditches, historic canalizations, lagoons. Here water is both an element to be contrasted, as demonstrated by the numerous reclamations works carried out over the centuries, and an attractive element for settlements.

Human presence is documented since the Lower Palaeolithic in various connections with watercourses and basins. In Protohistory and in the archaic period the coastal settlements rose and developed at the mouth of rivers, ditches or built canals.

The fundamental break in the settlement process in this area is represented by the Roman conquest in 338 BC. This event determined a series of dynamics that are outlined in this contribution in the light of the relationships of urban centres with Rome and among themselves.

In this territorial and historical-archaeological context, the analysis of the role and exploitation of watercourses and lake basins until recent times is also fundamental. They have had multiple functions in the field of communications, as waterways used with inland waterway navigation techniques, in the field of reclamation, as collectors of stagnant water in subsequent hydraulic regimentation works, and have been used as basins for fish supply.

In the paper *Diagnostics and Conservation of coastal Archeological sites: the case study of the Roman Villa of Casignana, Reggio Calabria (Italy)* M. A. Zicarelli Barca, M F La Russa, A. Macchia, L. Randazzo, M. Ricca, S.A, Ruffolo examine the Roman coastal Villa of Casignana, dated back to the 4th cent. AD and known for its valuable mosaics. The structures of the Villa are partly submerged. In addition, the archaeological area is crossed by SS 106 Jonica and by the railway.

For centuries the site has been exposed to the risk of natural and human damage, ranging from erosion and rising sea levels to modern urbanization. Preserving the site involves a multi-disciplinary approach that includes archaeological, environmental, engineering expertise and the involvement of the local community.

For some years now, the University of Calabria, through the Restoration course and the Heritage Science Research Group, has been engaged in strategies related to the conservation and enhancement of the site.

The mosaics suffer several degradation forms such as salt crystallization, deformation, deposits and lacks. The single *tesserae* are investigated in order to gain information about the composition and the provenance of the stone materials used by the Roman artisans.

Within the framework of the national PNRR "Tech4You" project, the Villa has been chosen as a pilot site for the identification of innovative technologies aimed at the conservation of cultural heritage, in the frame of the climate change and the transformations of shorelines.

Experiments are underway to define the use of innovative and environmentally sustainable products for the mitigation of the biodeterioration, based on essential oils and agricultural by-products.

These strategies will be tested on site after the necessary laboratory tests. As the involvement of the local community is crucial for the sustainable conservation and lasting success, outreach initiatives, educational activities and guided tours will be organised.

In *When geology becomes cultural wealth: Praia a Mare, town of caves* G. D'Ecclesiis and A. Pellettieri present a specific case study.

The territory of Praia a Mare (Cosenza, Italy) is characterized by the presence of many caves both on the coast of the mainland and the adjacent island of Dino. These caves have been frequented by man since the Paleolithic era. The largest one provides geological evidence of sea level changes and human activities, in particular prehistoric depictions on the walls. At present the cave houses the Sanctuary Madonna della Grotta, patron saint and protector of Praia.

Since the early Middle Ages other caves were occupied by Greek monks, who established monasteries and places of worship. According to tradition, the local hero Vitigno defended the city from an assault by the Turks in 1639 and died in a cave on the Dino Island.

Since many caves in the Praia district are connected with the most ancient history and/or with the most deep-rooted local traditions, a census and when necessary a recovery from vegetation and debris as well as a careful protection from the sea were carried out. These interventions were aimed at including the caves in a tourist itinerary accompanied by information panels.

In *The building materials of the Lorenese forts of the Tuscan coast*, S. Rescic, F. Fratini, M. Mattone examine the natural and artificial (bricks and mortars) stone materials used in the construction of the fortifications realized by the Grand Duke of Tuscany Pietro Leopoldo between 1786 and 1793 along the Tuscan coast.

The studied buildings are part of the complex coastal fortification system of Tuscany, that overall includes 160 fortified centres, individual fortresses (or redoubts and batteries), watchtowers and accommodation for soldiers and cavalry guards. They have been constructed in the time span from the Middle Ages to the 19th century and remained largely intact until the unification of Italy.

The research aims to identify the relationships between the building materials and the resources (stone, clay and limestone for the production of lime) in the territory, or to ascertain a standardized use of materials coming from a single production center.

In addition, the state of conservation of the structures and the decay phenomena are studied, in order to identify the role of environmental factors in relation to the characteristics of the building materials.

The applied methodology includes the classic mineral-petrographic techniques.

F. Benincasa, M. De Vincenzi and G. Fasano, all with a technical-scientific background, explore multidisciplinary, mainly historical themes and propose themes on ancient navigation to researchers in various disciplinary fields. In *Ancient navigation and Mediterranean coastal meteorology*, they consider several aspects of ancient navigation in the Mediterranean Sea. They examine problems associated with coastal or offshore routes, the experience of sailors, the winds and currents and underline the fact that sailors relied largely on personal experience. As documented by ancient written Greek and Latin sources, ancient sailors tried to pick up on warning signs from the sky, the flight of birds and the behaviour of certain aquatic animals, in order to predict weather changes.

In *The historic lighthouses of the Italian Coasts*, the same authors deal with a topic closely related to navigation: the function and history of lighthouses. They examine the origin of the name *pharos*, the techniques and instruments used to assist navigation in the dark, the fuels used to produce lighting, the architectural characteristics of the buildings, etc., and draw attention to several historic lighthouses in Italy, outlining the historical-geographical-geomorphological contexts in which they were built.

Once again, my invitation is to read carefully all these works, which have ensured the success of the session.

I would like to express my warmest thanks to all the authors for their participation in the conference and their commitment to present the results of their research to the scientific community.

For their continued advice and active participation in the organization of the scientific work I am especially grateful to Michel Gras, co-chair of the session (former Director of the École française de Rome, Emeritus CNRS, Foreign Fellow of Accademia dei Lincei), to Peter A.J. Attema (University of Groningen), Giovanna Bianchi (University of Siena), Giulio Ciampoltrini (former official Soprintendenza Archeologica per la Toscana, Firenze), Elif Koparal (Mimar Sinan Fine Arts University, Istanbul), Tessa Matteini (University of Florence), all of them members of the Scientific Committee.

Finally, I extend my best thanks for the event and for the publication of these Proceedings to the President of the Conference Marcantonio Catelani (University of Florence) and to all the organizers, in particular to Fabrizio Benincasa, Laura Bonora, Matteo De Vincenzi, Giorgio Matteucci (CNR-IBE, Florence): without their invaluable and patient work the realization of the Symposium would have been impossible.

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COASTAL ARCHAEOLOGICAL EVIDENCE IN THE BAY OF NAPLES: VULNERABILITY AND ISSUES OF CONSERVATION AND ENHANCEMENT

Claudia Aveta

Abstract: There is no region in Italy and, perhaps, in the world that presents such a wealth of archaeological evidence, even underwater, as Campania and, in particular, along the coasts of the Bay of Naples: a site that includes all the territories bordering the gulfs of Naples and Pozzuoli, including the islands of Procida, Ischia and Capri.

It is precisely the extraordinariness of this richness that makes it a particularly complex case, bearing in mind that we are dealing with highly urbanised areas and, therefore, decidedly exposed to human action.

This contribution attempts to outline the complex problems of the coastal archaeological areas, including underwater areas, in the Bay of Naples, starting from the definition of their consistency and varied typology and the phenomena of degradation that characterise them, to arrive at a definition of the risks to which they are exposed and to point out possible directions consistent with desirable urban regeneration processes: among these are the significant experiences of the submerged archaeological parks of Baia and Gaiola.

Keywords: Bay of Naples, archaeological evidence, valorisation, conservation

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Claudia Aveta, *Coastal archaeological evidence in the Bay of Naples: vulnerability and issues for conservation and enhancement*, pp. 529-540, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.47

Foreword

There is no region in Italy and, perhaps, in the world that presents such a wealth of archaeological evidence, even underwater, as Campania, in particular, along the coasts of the Bay of Naples: a site that includes all the territories bordering the gulfs of Naples and Pozzuoli, including the islands of Procida, Ischia and Capri.

It is precisely the extraordinariness of this richness that makes it a particularly complex case, taking into account that we are dealing with highly urbanised areas and, therefore, decidedly exposed to anthropogenic action, in addition to natural action. We are faced with values of exceptional interest for the history of the civilisations that have succeeded one another in these territories, from the Greeks to the Romans, and even before, characterised, however, by great fragility and vulnerability, as they are exposed daily to damage, theft and tampering of all kinds by man, but also to the effects of natural events and disasters, such as the seismic and bradyseismic events that have cyclically occurred throughout history and up to the present day.

Thus, coastal archaeological evidence, even on an urban scale such as Pompeii, is an integral part of a palimpsest of artefact values in continuous transformation due to the combined action of nature and man, who intervene on them with transformations that overlap over time, contributing to increasingly weakening the recognisability of these sites, which thus lose strength in the memory of the community and also risk their very perception. We witness, on the one hand, the alteration and loss of their spatial configuration caused by the intense exploitation of the coastline and, on the other, the continuous and incessant phenomenon of naturalisation of the ruins due to the dynamic action of coastal environmental conditioning, even though the fascination of all the classical remains scattered along the coastline of the Gulf of Pozzuoli and Naples remains. Here one encounters urbanised areas, even disused industrial areas and ports, heavily built-up areas, with a historic centre of extraordinary extension and value, UNESCO heritage sites (Naples) or minor ones (Pozzuoli, Castellammare, etc.), archaeological sites, even submerged ones, agricultural areas, other areas in their natural state. From the west are the Phlegraean Fields, Naples, the Vesuvian coast, the Sorrento coast and Capri; at sea are the Protected Marine Areas (Regno di Nettuno, Parco sommerso della Gaiola, Parco sommerso di Baia[1], Punta della Campanella; then, the Riserva Naturale Statale Isola di Vivara); the Area Naturale Protetta Baia di Ieranto.

These are coastal sites, rich in cultural heritage, expressions of the way in which man has shaped and transformed nature to adapt it to his needs, true Historic Urban Landscapes. The settlements found their historical reason in commercial needs, in relations with other coastal populations: thus, they constituted means of connection between civilisations.

The significance of these territories must be interpreted for the purposes of protection, yes, but also of valorisation, with a dynamic and no longer passive or

[1] This park is the first Italian underwater site to receive UNESCO recognition as 'good practice' for the conservation of underwater cultural heritage.

anachronistic approach based on integrated conservation of the existing. A cultural analysis of the coastal territory is useful for this purpose: starting with historical and iconographic data. A cultural analysis of the coastal territory is useful for this purpose: starting with historical and iconographic data. In this type of multidimensional investigation, complex factors emerge: the diversity and affinities of coastal sites from a geomorphological point of view; geological features; high coasts with accessibility problems, landslide risk and prospects for natural engineering interventions; disused industrial areas; low coasts: bathing sites and the protection of coastlines; commercial and tourist ports; historic harbours and villages; coastal archaeological sites and submerged archaeology; sea beds, protected areas and reserves. In short, it is necessary to seek ways in which these complex coastal systems, whose intrinsically dynamic character has lent itself and continues to lend itself to being crystallised and musealised, can be protected and conserved and enhanced. It is necessary to combine the conservation of such extraordinary but fragile sites with the sustainable development of local communities.

The richness of the coastal archaeological heritage in the Bay of Naples

A first theme is related to the consistency and value of archaeological sites on land or emerged due to bradyseismic phenomena and those submerged in the sea. Both typologies are unique in the Bay of Naples, bearing witness to the stratified history of the various civilisations that have inhabited these sites since antiquity. The first from the 8th century BC dates back to pre-colonisation, a real territorial conquest: the presence of Mycenaean settlements is attested by the discovery of ceramic artefacts in both Pithecusa (Ischia) and Vivara. Greek colonisation proper, developed from the 8th century B.C. onwards. Campania saw the arrival of the Euboeans, from the cities of Eretria and Chalkida, who founded Pithecusa and Cumae, while later the Cumanians founded other Greek cities in the region such as Neapolis. The location of the various populations in the area of present-day Campania at the end of the 6th century BC is taken from Strabo’s Geography and Pliny the Elder’s Naturalis Historia.

After the Romans occupied the territories of Campania with multiple conflicts during the 3rd century B.C., taking them away from the Samnites, Lucanians and Bruttii, and after the pax romana, the Campanian coasts were much frequented by the imperial family and the nobility of Rome, as the remains of the many villas and patrician residences along the coast testify. The ports of Campania were also important in Roman times, both for commercial traffic and for arming the military fleet.

Following the fall of the Western Roman Empire, the centres on the coast suffered attacks and devastation from invading peoples, including the Saracens, who landed in Sicily in 828 AD. Some of the ancient coastal settlements disappeared, others survived, and still retain the memory and culture of the civilisations that generated them.

As for the extraordinary wealth of archaeological evidence to be found along the coasts, starting with those in the Gulf of Pozzuoli, we indicate the main testimonies, referring you to the extremely rich bibliography of studies and research.

In the Phlegraean Fields, the island of Ischia, ancient Pithecusa, shows important findings of its ancient origin, starting with Mycenaean ones. In the municipality of Lacco Ameno, the vast necropolis of San Montano shows the maximum development of the settlement between 770 and 700 BC. In the first half of the 8th century B.C., a group of Euboic settlers settled on Mount Vico, at the base of which is the aforementioned necropolis at San Montano. Grave goods testify to the presence not only of the Greeks, but also of the Phoenicians: Mycenaean painted pottery from the 14th century B.C. shows a continuous stratification of the settlement from the Bronze Age to the 1st century B.C. There are still traces of the acropolis with remnants of Greek walls and Roman or late Roman tombs at the foot of Monte Vico. In the locality of Mezzavia, remains from the 7th century B.C. also indicate an earlier Mycenaean period. Other archaeological evidence can be found in the locality of Castiglione and under the church of S. Restituta in the Museum. In the municipality of Ischia, on the promontory of S. Pietro, which closes the harbour basin to the west, sea erosion on the eastern side has uncovered remains testifying to the existence of a Greek village; important findings were made a few years ago in the waters of Cartaromana. The ruins of a Roman thermal building at the hot springs of the Regina Isabella Hotel are still remembered.

On the islet of Vivara, which is connected to Procida, interesting finds dating back to the Middle and Late Bronze Age (15th to 12th century B.C.) have been unearthed, as well as fragments of Mycenaean-made painted pottery from the mid-14th century B.C.

At *Torre Gaveta*, which was part of Cumae, remains of buildings from the Roman era have been preserved, such as cisterns, parts of rustic villas and other testimonies from the 3rd century B.C. *Miseno*, with its natural harbour of the Cumani, has traces of an ancient settlement dating back to the 6th century B.C.: it assumed great importance in the Augustan age, when it became the base of the Roman military fleet in the southern Tyrrhenian Sea. The remains from the Roman period are: the port, the town centre (cisterns, tombs, parts of villas and the theatre, the Sacellum of the Augustals), the Piscina Mirabileis, the cistern for supplying the fleet built in the Julio-Claudian period. In *Bacoli and Baia*, from the 1st century B.C. and throughout the imperial age, villas and rich residences were built: the Tomb of Agrippina, columbaria, the Cento Camerelle. These sites are subject to bradyseismic phenomena - currently undergoing dramatic recovery - and many archaeological remains are submerged in the sea. In Bacoli there are the Cento Camerelle, the oldest cistern system in a private villa; the Piscina Mirabilis, an imposing cistern from the first half of the Augustan age built for the benefit of the Misenate fleet; the Sepolcro di Agrippina, the remains of the cavea of a small *odeon* of a maritime villa. Bacoli was the Port of Cumae in Greek times and owes its greatest development to the imperial era, when the thermal springs began to be exploited, becoming the site of a holiday resort for wealthy Romans, who built numerous villas there. It is enough to mention the complexes of extraordinary value such as the Baths of Mercury, those of Sosandra, the Temple of Venus and the Temple of Diana.

In terms of underwater archaeology, Baia constitutes one of the largest and richest archaeological areas in the entire Mediterranean Sea. From the first discoveries in its waters in the 1920s to the present, it was only in recent years that a marine protected area was established in 2002. Surveys and studies were carried out in the late 1950s by N. Lamboglia and A. Maiuri; the excavation of Punta Epitaffio was directed between 1981-82 by F. Zevi and B. Andreae and conducted by P.A. Gianfrotta. A highly articulated topographical picture emerged, highlighting how the port complex of Lucrino and that of Puteoli constituted an integrated system of military (Portus *Iulius*) and commercial (*Ripa puteolana*) infrastructures. In 1987, the Superintendence imposed an archaeological restriction on the 500-metre strip of sea that runs from the port of Baia to the stretch of coast facing Lake Lucrino to safeguard the remains of *Portus Iulius*. In 1998, the same Superintendency was granted the management of a large stretch of sea of about 80 000 square metres to initiate a research and enhancement programme. Finally, in 2002, the Ministry of the Environment and Protection of the Territory, in agreement with other Ministries and in agreement with the Campania Region, established the aforementioned Underwater Archaeological Park of Baia, together with that of Gaiola, equated to a protected marine area, with the subdivision into three zones with different degrees of protection.

Pozzuoli, the ancient *Dicearchia*, founded in 530 B.C., was under the rule of the Samnites, until it became the most important Roman port from 215 B.C. onwards: it was extraordinarily important between the 2nd and 1st centuries B.C. Famous for its thermal waters, the town survived even after barbarian invasions and bradyseismic phenomena. Its most significant Roman monument is the Flavian Amphitheatre, the third largest in the Roman world, after Rome and S. Maria Capua Vetere. Most notable is the Macellum, known as the Temple of Serapis.

In the Gulf of Naples, then, between the Neapolitan capital and Castellammare di Stabia, there are centres of varying size and importance:

Naples: the archaeological testimonies of the historical centre of the Neapolitan capital, a Unesco heritage site, are well known. Recent discoveries have also uncovered artefacts of port structures, uncovered during work on the new Metro line. There are also many archaeological remains submerged in the sea: the Gaiola park deserves special attention: here, one marine protected area has been identified as an integral reserve (the two islets of Gaiola and the Trentaremi caves) and the other as a general reserve, which includes the entire Trentaremi bay, a large part of the rocky bank of the Gaiola and Cavallara shoals, as well as the stretch of water in front of the Marechiaro village. Going down the Gaiola descent, one finds the remains of the Roman villa of Vedio Pollione, one of the most striking examples of maritime villas, which stretches along the portion of the hill between Trentaremi Bay and Cala dei Lampi, as far as Marechiaro.

In *Portici*, numerous archaeological finds from Herculaneum are preserved in the Royal Palace: a mosaic floor, the statue of Victory decorating the Fountain of the Sirens, the statue of Flora. *Herculaneum*, damaged by the earthquake in 62 A.D., was buried by the eruption of 79 A.D.; the archaeological city owes its main discoveries to A. Maiuri for the main findings. In *Torre Annunziata*, in the ancient *Oplontis* partly buried under the modern settlement, the Villa di Poppea, partially destroyed by the earthquake of AD 79, stands out. *Pompeii* is one of the most important archaeological sites in the world and in recent decades the continuous discoveries, both of artefacts and evidence of material culture, have further enhanced its historical-documentary value. *Castellammare di Stabia*, the ancient *Stabiae*, was first destroyed by Sulla in 89 BC and then by the eruption of Vesuvius in 79 AD. The archaeological remains consist of parts of Roman villas from the early imperial age, including those *maritimae*, on the Varano hill.

Continuing along the Sorrento coast we find: *Vico Equense* with traces of necropolis related to the pre-Roman period, including that of Via Nicotera (7th-5th century B.C.), discovered in 1892, with elements of Etruscan production, the remains of which are preserved at the Antiquarium in Corso Umberto. There are also the few ruins of the Villa at Marina di Equa, as well as walls and cisterns below the Pacognano settlement, the fossils at Capo d'Orlando, and the caves. In *Piano di Sorrento*: the ruins of Villa il Pizzo near the coast. Sorrento is the ancient *Surrientum*, possibly founded by the Greeks. It was a holiday resort of Roman patricians, as the remains of the so-called Villa di Pollio Felice at the Capo di Sorrento testify, with the maritime part found at the small basin known as *Bagni della Regina Giovanna*. At *Massa Lubrense* and *Punta della Campanella* there is the Villa at Capo di Massa, and the one at the aforementioned Punta: here there are the remains of a sanctuary dedicated to Athena, later adapted to the cult of Minerva, where Robert D'Angiò then had the Minerva Tower built in 1335. The ancient *sacred way* still exists with its route from Termini to Punta Campanella.

On *Capri*, the most important remains from the early imperial age are the villas where Augustus and Tiberius stayed. Archaeological sites and assets are of great importance: the prehistoric remains at Valletta di Tragara; fortification walls of the Greek acropolis from the 5th-4th centuries BC, Villa Jovis on the north-eastern promontory of the island, the Bagni di Tiberio on the coast near Marina Grande, the *opus reticulatum* walls at Castiglione, caves transformed into nymphaea, such as at Matromania, Arsenale, Castiglione, the remains of a Roman landing at Tragara.

Anthropogenic and natural hazards between land and sea

Natural hazards to which archaeological evidence on land is exposed include a number of aspects: salt crystallisation of stone materials, seismic and bradyseismic events.

The first, in particular, concerns porous materials, and represents one of the most insidious forms of degradation for artefacts such as buildings, bridges, roads.

For seismic events, cyclically repeated over the past centuries and up to the present day, the Vesuvius Observatory evaluates the data collected to understand their nature and impact. The Phlegraean area, then, is subject to slow soil deformation known as bradyseism (slow soil movement) that occurs in different ways over time, leading to both uplift and subsidence of the soil. This natural phenomenon is also making its effects felt under the sea and, albeit slowly, the earth's crust is also rising to the seabed.

For terrestrial archaeological assets, the *Great Pompeii Project* is of significant reference, which aimed to strengthen the effectiveness of protection actions and interventions in the archaeological area.

This Project stems from an action of the Italian Government that, through Decree-Law no. 34/2011, allowed for the development of an Extraordinary Programme for Conservation, Prevention, Maintenance and Restoration. Financed in 2012 within the framework of the Interregional Operational Programme Cultural, Natural Attractions and Tourism (FERS 2007-2013), its implementation developed in two phases: the first completed in 2015, the second in 2022. The implementation programme was divided into five major Plans, investing in 76 different interventions amounting to more than EUR 105 million and ultimately representing a *best practice* in the spending of EU funds in terms of objectives achieved and spending and reporting capacity.

It was an exceptional operation, which changed the face and image of Pompeii and which, in addition to solving the problems of the physical conservation of the archaeological evidence, addressed the new anthropogenic risk determined after the end of the pandemic: the excessive number of visitors and its effects on the fragile archaeological context. Referring to the many publications on the recent restoration of archaeological Pompeii, here we highlight how, thanks also to multiple university agreements - which have fostered the contribution of many scientific disciplines, and thus the fundamental multidisciplinary contribution needed to tackle the complex problems of restoring archaeological evidence - a shrewd coordination of the impressive flow of visitors has been carried out, with well over 3 million visitors in 2023: an increase in the opening hours of the excavations and the differentiation of routes have been planned.

To the many problems of excavation, conservation and valorisation of above-ground finds - tackled by archaeologists with the support of architects, engineers, art historians, chemists, physicists and many other professionals - are added the problems of the numerous submerged archaeological remains in the Bay of Naples.

Submerged archaeology between standards, guidelines and practice

As previously highlighted, there are many extraordinary underwater archaeological evidence in the Bay of Naples, towards which the attention of Italian governments has turned in fairly recent years: in fact, a specific reference can be found in the Code of Cultural and Landscape Heritage (Legislative Decree 42/2004). In the second section there is Article 94 (Unesco Convention), there is a rule prescribing the discipline contained in the annex of an international convention on the protection of the underwater cultural heritage: this is the one adopted by the Unesco General Conference on 2 November 2001 in Paris. This contains specific regulations to protect the underwater heritage understood as every trace of human existence of a cultural, historical or archaeological nature that has been wholly or partially submerged for at least one hundred years, and is supplemented by an annex consisting of 36 *Rules on Underwater Cultural Heritage Interventions*. In the above-mentioned article of the Code, reference is made to assets found on the seabed in the sea area extending twelve nautical miles from the outer limit of the territorial sea.

In addition to the regulations in force in Italy, there are also the Conventions and Charters that have been registered at international level, which testify to the increasing awareness towards the protection and conservation of this particular type of cultural heritage in recent decades. The following are worth mentioning: *The international Charter on the protection and management of the underwater cultural heritage* (ICOMOS 1996); *Syracuse Declaration on the Cultural Heritage of the Mediterranean Sea* (Syracuse 2001); *Convention on the Protection of Underwater Cultural Heritage* (UNESCO 2001); *Protocol on Integrated Coastal Zone Management in the Mediterranean* (Council of Europe 2008).

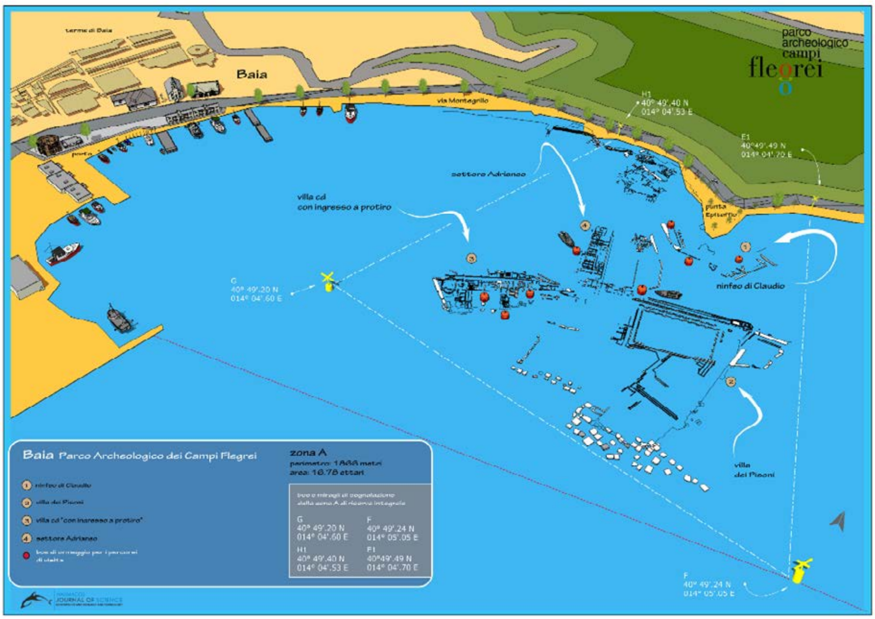

Figure 1 – Archaeological routes in the Baia Underwater Park. (https://www.parcosommersobaia.beniculturali.it/it/percorsi-archeologici).

Demonstrating the special interest in underwater archaeology in recent years is a series of studies and research, some of which have been completed, some of which are ongoing. Among the former is the *Arrows* project for the use of robots in archaeological research, tested both in the Baltic Sea and in the Mediterranean Sea, in completely different contexts, with the participation for the Italian side of the University of Florence, CNR-ISTI, EdgetLab srl and the Department for Cultural Heritage and Sicilian Identity. Also, the COMAS Project, which developed methodologies, techniques and new materials for the restoration of underwater heritage in situ. Participants included UNICAL, Whitehead, Sistemi Subacquei, Ageotec, Syremont, ISCR and the Scuola Superiore di S. Anna in Pisa. The *THESAURUS* Project has developed underwater robots, methodologies and multidisciplinary scientific technologies to locate, survey and document artefacts and wrecks of archaeological, historical-artistic and ethno-anthropological value:

these are underwater reconnaissance methods using optical, acoustic and magnetic systems. The *Restoring Underwater* Project, which lasted about twenty years, studied tools, materials, methodologies and techniques for the *in situ* restoration of submerged ancient artefacts, and was commissioned by the Istituto Superiore per la Conservazione ed il Restauro and MIBACT. The *VISAS* Project is aimed at enhancing the value of underwater archaeological sites through the implementation of augmented reality and virtual reality services: it was developed by Dimeg Unical University of Calabria, CNR Iamc, 3D Research srl, Applicon and Enviroconsult.

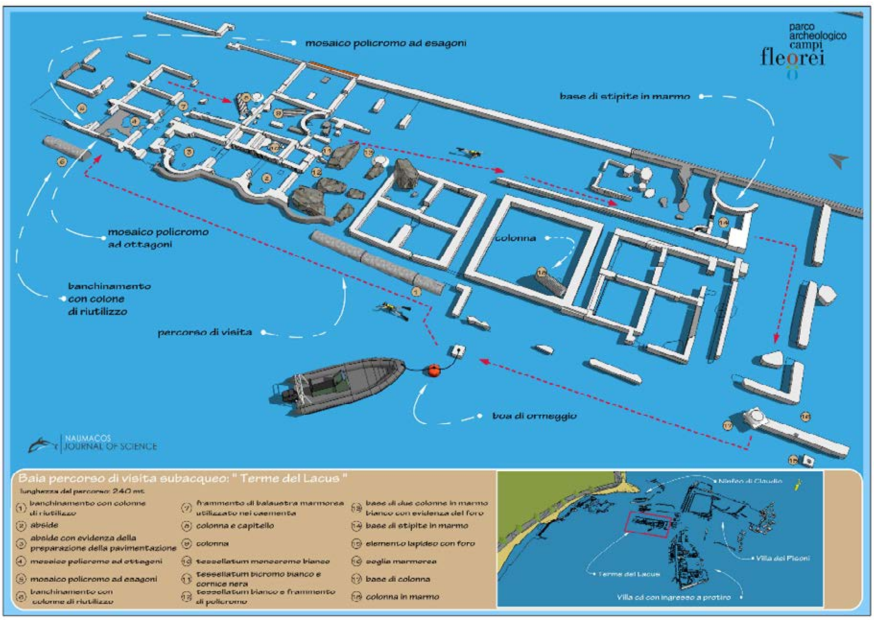

Figure 2 – Baia, underwater tour: Lacus Baths. (https://www.parcosommersobaia.beniculturali.it/it/percorsi-archeologici).

Ongoing research includes the *MUSAS* Project (Museums of Underwater Archaeology) aimed at using advanced technological solutions for networking underwater and land-based archaeological sites, with applications in the underwater port of Egnazia. The *ARCHEOSUB* Project for the application of innovative solutions such as networks of underwater sensors placed on the seabed of archaeological sites to provide real-time and monitored data on artefacts: is carried out by the University of Rome la Sapienza, MDM Team, University of Florence, WSENSE. Furthermore, the *iMARECulture* Project is aimed at raising European public awareness of maritime cultural heritage through virtual tours, games with immersive technologies and augmented reality visits.

Since 2004, the General Directorate of the MIC has launched the *Archeomar Project*, which aims to census, locate and document the archaeological assets in the seabed in the southern regions of the country where cultural heritage is under the jurisdiction of the state administration (Basilicata, Calabria, Campania and Apulia). This is also to help improve the management and enhancement of underwater sites. Furthermore, in 2019 the National Superintendence for Underwater Cultural Heritage was established, which has its headquarters in Taranto and operational centres in the Archaeology, Fine Arts and Landscape Superintendencies of Naples and Venice.

In the case of submerged archaeological evidence the issues, compared to those on land, become considerably more complicated. In specialist research, the different issues have been addressed, at least from a methodological point of view, and only in some cases in specific applications.

When artefacts cannot be moved from the site, in situ protection systems are adopted, using geotextile and sand covers, metal tube structures and removable panels, polyethylene sheets and sandbags, silicon casings, etc., as appropriate. These are expedients of various kinds that can slow down or contain the phenomena of degradation in the marine environment and that, above all, seek to protect valuable evidence underwater from theft and vandalism.

The specific methodology is that of restoration, which starts from knowledge to arrive at the most appropriate interventions for the conservation and enhancement of the artefacts. Knowledge requires defining the morphology of the seabed, depth, currents, visibility and transparency of the water, sea conditions, the possible presence of pollutants, and the passage or stationing of boats. Then there is the knowledge of the physical alterations of the finds due to corrosion phenomena, encrustations of a biological nature, etc. There are many fields of scientific knowledge involved: archaeologists, underwater archaeologists, physicists, chemists, geologists, petrographers, architects, structural engineers, etc.: all of them are useful in the cognitive phase, both in defining the consistency of the finds and in diagnosing deterioration and disruption.

The survey phase also makes use of specific methodologies and technologies: from aerial photography to satellite surveys, acoustic and magnetic prospecting systems, such as Side Scan Sonar, Sub-Bottom Profiler, and Multibeam. To these are added photographic surveys with photomosaics and the use of photogrammetry. The use of robots is also of fundamental importance.

Similar complexity presents the definition of degradation processes and restoration techniques.

Thus, the submerged archaeological heritage in the Bay of Naples has extraordinary documentary value but requires a complex approach with multidisciplinary contributions, necessary to overcome the difficulties of the marine environment in which they are found.

Figure 3-4 – The statues of the Sunken Nymphaeum of Baia, photo by F. Lucci. (https://www.parcosommersobaia.it/statue-di-Baia.html).

Possible strategies and scenarios

The objectives to be pursued to enhance and redevelop coastal landscapes are many and among them are aspects that concern redevelopment policies to safeguard their diversity and variety and, therefore, to preserve the historical alternation of built and unbuilt spaces, in the spirit of containing further land consumption as much as possible; to consider the sea as a large public park of the Bay of Naples; to ecologically redevelop the settlements with a tourist function; to decompress the urbanised or industrialised coastal strip with appropriate delocalisation projects; to redevelop coastal landscapes in an integrated way within a Cultural and Ecological Network.

With reference to this last objective, which aims at the creation of a Network of territorial resources, the need for an analytical-cognitive process of the stratified history of coastal sites, up to the present day, is linked with the fundamental support of historical-iconographic, archival, bibliographic and urban planning research. They are, in fact, territories of extraordinary value, rich in physical and intangible cultural values linked to the civilisations and communities that have lived and transformed them over time: a true 'cultural mosaic' to be interpreted, protected and enhanced. The large number of archaeological evidences, also submerged, present along the coastal territory under examination and previously reported make Campania an absolute unicum in the national and international context.

It is desirable that in landscape policies the extraordinary value of these territories be enhanced for the multiple potentialities they express. Among these, that of constituting the fulcrum of a policy for the protection and enhancement of a context even wider than the coastal one. In a process of integrated valorisation of territorial resources, it is desirable that coastal archaeological areas, even underwater ones, can be part of a fruitive offer that is not limited only to these extraordinary sites, but connects them with the other types of cultural resources in which the context is rich (from historical centres to historical-artistic heritage, intangible assets and so on). Just think of the possible relationships with the many historical centres in the territories that can be reached by archaeological sites, coastal defence tower systems, castles, etc. A complex operation, but possible: enhancing the centrality of coastal archaeological sites requires the definition of a strategy that is shared and concerted by a set of actors, starting with the regional authority, the municipalities, the Superintendencies, the managers of Protected Areas, Parks and Nature Reserves, hotel associations, environmental associations, and the communities themselves. With joint actions, it will be possible, among other things, to trigger a process of greater awareness of the territorial resources present in the various sites; to achieve more efficient planning of the various activities and events, also for a better distribution of tourist flows; to carry out better maintenance and control of the territory; and to improve the accessibility of services, infrastructures and territorial systems. In essence, it is essential that a more effective *governance* structure be created for these territories.

In conclusion, the coastal archaeological areas of the Bay of Naples, if safeguarded and enhanced, may well be one of the drivers for a new model of social, economic and cultural development that is truly sustainable for local communities.

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ANCIENT NAVIGATION AND MEDITERRANEAN COASTAL METEOROLOGY

Fabrizio Beninicasa, Matteo De Vincenzi, Gianni Fasano

Abstract: For a long period, Greeks, Phoenicians, and Etruscans frequented, at the same time, the Mediterranean Sea. This forced their seafaring to behave, at the same time, as pirates at sea, to break down competition, and as traders in the *emporia*, to sell their goods.

Navigation was based on the experience of sailors since there were no instruments and methods to estimate sailing parameters. The empirical knowledge of seafarers was based on the observation of environmental and astronomical daymarks, and on their ability to perceive signals from the atmosphere, and from sea animals.

Navigation was mainly carried out at such a distance from the coast as not to lose sight of it; but in the Mediterranean Sea the coasts, often mountainous, allowed to have in sight elevated points of reference, which also allowed offshore navigation.

Merchant vessels were not as fast as combat, but they could carry large loads of various types to be sold in various emporia. The average speed of a ship was around 5-6 knots, therefore the longest voyages, could require considering stops for rest and bad weather. In this case the journey required a winter stopover, and the navigation continued into the following season. Therefore, we understand the importance of "weather forecasting" which could be done with a careful analysis of the warning signs that came from the sky, from the flight of birds and the behavior of fish and other aquatic animals.

Keywords: Navigation; Ancient Meteorology; Sailing techniques; Celestial Navigation

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

1. Introduction

It is not known with certainty which peoples crossed the Mediterranean first, but, for sure, the very long routes can be attributed to the Phoenicians, a population originating from the coastal strip of the Levant in the eastern Mediterranean which roughly corresponds to current Lebanon (13th century BC - 1st century AD). The Phoenicians, moreover, were the first to travel the entire coast of North Africa (see figure 1).

From the far easternmost part of Mediterranean, their place of origin, these merchants reached the far west, and around 800 BC. they passed the Pillars of Hercules[1] (Strait of Gibraltar) to Gadir (modern Cádiz, on the Atlantic coast in southern Spain). Considering the currents and winds the Phoenicians limited their sailing season to a very shorted period between late spring and early autumn, when the Mediterranean weather conditions are were almost stable [12]. D. Abulafia, in *The Great Sea* [1], shows the northerly route that they most likely followed "[…] *past Cyprus, Rhodes and Crete, then across the open expanse of the Ionian Sea to southern Sicily, southern Sardinia, Ibiza and southern Spain. Their jump across the Ionian Sea took them out of sight of land, as did their trajectory from Sardinia to the Balearics* […]" [1]. It is known that on the open sea the Phoenicians sailed at night, using the Pole Star as a reference which, for this reason, the Greeks called it the star of the *Phoenike* or *Phoenician star* [12]. Furthermore, the great help given to night navigation by beacons, precursors of lighthouses, which coastal populations kept lit in large braziers on: emergent rocks, skerries, sandbanks, and other dangers, should not be overlooked [8]. Homer, in the *Iliad*, compares the glittering shield that the god Hephaestus built for Achilles to one of these fires[2].

But it is also true that in the Mediterranean basin the coasts, often mountainous, allow high landmarks to be kept in sight even on the high seas. In the Mediterranean, in fact, the sea areas from which it is not possible to see land are very few and in areas of little interest to ancient sailors [12]. Hence our greater attention to navigation close to the coast over small or large distances, in other words small or large cabotage[3]. Greater attention that ancient sailors also had to have because sailing close to the coast, that can be more dangerous than offshore sailing. In fact, close to the coastline, there may be unpredictable rocks or currents and where the effect of the tides is felt more. For all ships, weather conditions were another risk factor because they could change suddenly and make navigation dangerous or even prohibitive.

In this paper, a sort of "immaterial archaeology", we will discuss the routes

[1] The ancient Greeks considered, at that time, the known land surrounded by an immense "river" called Ocean (*Ōkeanós* in greek): *even birds cannot fly the distance in a twelve-month, so vast and terrible are the seas that they must cross.* (Homer, *The Odyssey,* book III vv. 321-322 [21]).

[2] [Achilles] *he took the shield, / Massive and broad, whose brightness streamed as far / As the moon's rays. And as at sea the light / Of beacon, blazing in some lonely spot / By night, upon a mountain summit, shines / To mariners whom the tempest's force has driven / Far from their friends across the fishy deep,* (Homer, *Iliad* book XIX vv.450-456 [20])

[3] Cabotage: Coastal navigation or shipping especially within the borders of one country. From the French, from *caboter* to sail near the coast, apparently from the Spanish *cabo*, cape, headland, or promontory.

followed for trade and the meteorological surveys that were carried out before and during navigation. Since we cannot talk about all the cultures that, in various eras, were present in the Mediterranean, we will focus on the aspects that the seafaring of the Greeks, Phoenicians and Etruscans, in the same period, had in common. As regards to meteorology we will refer more to that developed by the Romans, who more than others made "signs" a "science", dictating rules and codifying survey procedures.

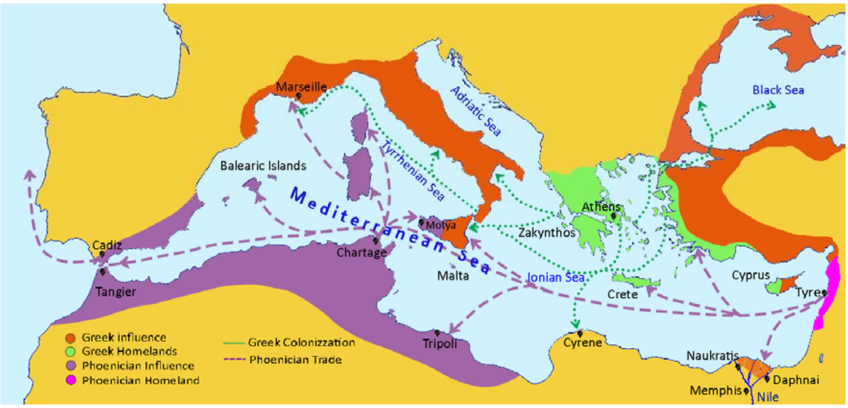

Figure 1 – The main trade routes (Graphic processing by G. Fasano).

2. The Mediterranean routes

2.1 The navigation

In ancient times, navigation was based on the experience and empirical knowledge of sailors since there were no instruments and methods to estimate sailing parameters (position at sea, direction and speed, weather, etc.). The empirical knowledge of seafarers was based both on the observation of environmental and astronomical daymarks[4], and on their ability to perceive and interpret every little signal from the atmosphere, from the wind, from the surface and from the seabed, and, as we will see, from the behavior of birds and animals that inhabited the sea areas.

The waters flowing from the Atlantic towards the Mediterranean (through the Strait of Gibraltar) generate currents. The main ones follow the coasts of Maghreb and, after passing Egypt, head towards Israel and Lebanon, reaching Cyprus; then, turning towards the west, they enter the Aegean Sea, the Adriatic and then the Tyrrhenian Sea from where, traveling along the French and Spanish coasts, they return to the Pillars of Hercules (figure 2). These sea currents have significantly facilitated sea trips within the Mediterranean because with them it was possible to navigate even in unfavorable winds.

[4] Daymarks are all those natural and artificial elements of remarkable size and height which have characteristics clearly visible and recognizable from the sea. For example, daymarks are mountains, promontories, buildings along the coast (towers, lighthouses, bell towers, etc.).

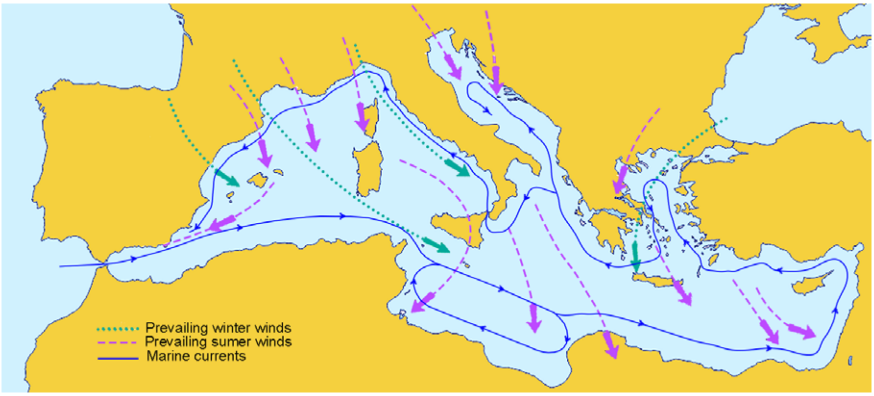

Figure 2 – Marine currents and prevailing summer and winter winds (Graphic processing by G. Fasano).

Table 1 – The winds of the Mediterranean Sea.

Origin	*Symbol*	*Greek*	*Latine*	*English*
North	N	*Boreas*	*Septentrio*	Tramontana
North-East	NE	*Kaikias*	*Aquilo*	Gregale
East	E	*Apeliotes*	*(Sub)Solanus*	Levant or levanter
South-East	SE	*Euros*	*Vulturnus*	Sirocco or Scirocco
South	S	*Notos*	*Auster*	Ostro or auster or ostria
South-West	SW	*Lips*	*Aphricus*	Libeccio
West	W	*Zephiros*	*Favonius*	Ponente
North-West	NW	*Skiron*	*Caurus*	Mistral or *Maestro*

In winter the western Mediterranean is influenced mainly by the North Atlantic weather system and in summer by the high pressure of the subtropical Atlantic, which is stationed over the Azores. The air currents in the Mediterranean region move mainly from West to East so in spring-summer the winds can be used to sail from the ports of Catalunya, Ligurian Sea, and northern Tyrrhenian Sea towards: Sicily, Sardinia, and the Levant [16]. The importance of the winds is shown by the personification that all cultures have made of them, in particular the Greeks considered the winds of divine origin, as Hesiod indicates in the Theogony [6], giving them a name in relation to the direction of origin with respect to the island of Zakynthos (Ionian Sea); while other cultures referred them to the "central Mediterranean".

All sailors knew the direction of the winds in relation to the four cardinal points (*Compass Rose*): north, east, south, west to which four intermediate winds were added (see table 1). Other names of half-winds (and successively quarter-winds) were added over time until first twenty-four and then thirty-two were classified [7].

Only the knowledge of marine and air currents allowed ancient sailors to develop navigation, rightfully considered a *téknē* (art in Greek). This art began when the "ship" was a tree trunk dug out and moved, on the water of a river or lake, by the force exerted by human being on an oar. The need to carry out longer navigations led humans to integrate their strength with that of the wind. The sail made it necessary for greater transversal stability of the "ship", which was obtained by equipping the trunk with a lateral outrigger[5], or by widening the hull in the central area. The Egyptian ships, of which there are traces since 4000 BC, were of this second type; their hull was made of bundles of papyrus stems, tied together, and the sail was supported by two "masts", arranged in an inverted V, fixed to the sides of the hull. The sail was made with skins joined together and square-shaped, as time passed the skins were replaced by a sturdy fabric[6]. Since 2000 BC the papyrus stems were replaced by sycamore or acacia wood boards, and the support of the sail became a single central mast, which could be removed. Moreover, two short oars, with large blades, were placed at the stern to steer the ship which, thus equipped, could leave the Nile and sailing the sea. [25].

The first Phoenician ships were very similar to the Egyptian ones, but the wood used was much better. In fact, the large cedars of Lebanon, with trunks up to 40 m, allowed the manufacturing of much more robust and much larger hulls. Similar nautical structures were built by the Greeks who, however, used pine wood.

Over time, two types of vessels were designed by the Phoenicians: warships and trading vessels. The first characterized by easy maneuverability and speed, the second (of greater interest for our purpose) by a greater loading capacity of goods and people. As a result of this, the propulsion of combat ships was entrusted to sails and oars, in order to ensure speed of maneuver and movement regardless of the intensity and direction of the wind. In the latter the propulsion was mainly entrusted to the sails to minimize the crew and thus maximize the space for goods. Furthermore, in warships the hull was slender and the lower freeboard than in cargo ships, in which the hull was more rounded and higher freeboard. The Phoenician tradition was also followed by the Greeks who, however, used metal anchors [25].

The Romans modified the structure of the Phoenician ship by adding a second mast at the bow, very inclined forward, with a second square sail.

As for the rowers, they were arranged in symmetrical rows on both sides of the ship; there could have been more than one row on each side, but whether they were side by side or overlapped has not yet been demonstrated. *Experimental archeology* has shown that in both cases there could have been interference in the movements of the rowers, due to the limited space in relation to their number which could reach 150.

An accurate description of ancient ships can be found in the didactic poem *La Nautica* (tr. *The Seamanship*), by Abbot Bernardino Baldi (1553 - 1617), published in Venice (1590), in four books [5]:

• *First book*: distinction of ships, their shapes depending on use and fitting out.

[5] Catamaran from Tamil word *kattumaram* meaning tied timber. Tamil is a Dravidian language of Tamil Nadu, state of south-eastern India, and of northern and eastern Sri Lanka.

[6] In reference to sails, the most important innovation occurred with the introduction of the *lateen sail*, widely used by Byzantines in the warship dromones, and become common in the Mediterranean starting from the 5th century AD. The term is probably from Arabic and indicates a triangular sail (from french *voile latine* and in turn probably from italian *alla-trina* contracted in *latina*, also meaning easy, simple, effortless) therefore different from the square sail rigged on yards [10], [35].

- *Second book*: celestial spheres, names of the seas, tides, signs of storms.
- *Third book*: the practice of loading ships, sailing, and steering during periods of calm and stormy seas.
- *Fourth book*: the places of the world where different goods are brought.

The sources relating to ancient ships never talk about the speed of the ship, but simply indicate the length of the journey, from port to port, expressed by days of navigation. Normally in offshore navigation, in one day, a longer route was covered than in coastal navigation, where shallow waters, rocks, tides, etc., they could slow down navigation. In any case, however, weather conditions had to be considered: The good weather with regular and favorable wind made it possible to cover a longer stretch of sea than could be done in calm or rough seas. In the latter case, on the contrary, the ship had to be slowed down so that it was not overwhelmed by the sea and the wind that hit it from the stern [26].

2.2 The trade

Copper (from the 3rd millennium BC) and tin (from the 2nd millennium BC) were used to produce bronze and were at the center of the great commercial flows of the Mediterranean. Evidence of these flows are the wrecks loaded with ingots of these metals that were found in the Corsica Channel and in the Strait of Bonifacio. The iron metallurgy spread across the Western Mediterranean only in the 1st millennium BC; the rich deposits of the Elba Island, and of the facing territory of Populonia, made the northern Tyrrhenian Sea a great "industrial hub". The strong production of charcoal, necessary for the iron processing, led the Greeks to call Elba Island *Aethalia* (*Smoky Place*). The better quality of the iron ore mined from the Colline Metallifere of Etruria (Tuscany) and from the mines of the Elba Island made it preferable to that extracted from the Corsica mines. On the other hand, Corsica was rich in copper in the hinterland of Aléria (port at the mouth of the Tavignano river on the east coast); this led to the creation of favoured connections in the exchange of metals, for example Corsica exchanged its copper with iron from Populonia [31]. In the archaic Mediterranean, an area of intense traffic, trade was based on a real network of *emporia,* i.e. important trade centers located mainly on the coast, which served as markets for the collection (storage) and distribution of various goods for one or more regions [17], where Etruscans, Greeks, Phoenicians, etc. lived together, albeit in different areas.

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The merchant vessels sailed almost exclusively in the period between March and October, that is, in stable weather conditions and with clear skies which allowed night navigation by orienting themselves by the stars. Special ceremonies, addressed to the protective deities of sailors, preceded the beginning of the sailing season. Only the navigation of the large ships that sailed the high seas stopped completely in winter;

the little coasting knew no pauses. The *Acts of the Apostles* talk about the winter navigation in relation to voyage of Saint Paul and his companions to Rome: *Since the harbor was unfavorably situated for spending the winter, the majority planned to put out to sea from there in the hope of reaching Phoenix, a port in Crete facing west-northwest, there to spend the winter* (*Acts of the Apostles*, 27, 12 [33]).

Navigation followed this seasonal rhythm until the 14th century, when the use of the compass and the development of nautical charts allowed pilots to orient themselves even in overcast skies. Thenceforth, voyages began to be carried out throughout the year, although it was preferred to avoid sailing in the winter months [26].

Often on longer voyages, in the western Mediterranean and even more so in the Atlantic Ocean, warships were also used for trade purposes. This was due to the very frequent conflicts that arose between the Greeks, Phoenicians, Carthaginians, and Etruscans; they all played a dual role: pirates at sea and traders in the ports. Because of this, for the precious goods transport, which by their very nature had little volume, ships were used with little loading capacity but with characteristics such as to guarantee the possibility of both defence in the event of assault and danger, and attack in case of necessity. For this purpose, the Greeks used a ship, called *penteconter* or *pentekonter* (from the Greek *pentēkóntoros* derived from *pentēkonta* = fifty, in reference to the number of oarsmen). It was steered by means of a central stern rudder together with two lateral blades wider than an oar, a system that allowed both fast paces even on tortuous and treacherous routes, such as coastal navigation, and high maneuvering agility in ramming actions [15], [18], [30].

In the Phoenician *trireme* there was a compromise between agile maneuverability and high speed, which was made possible by small masses and dimensions combined with many rowers. In the proximity of the battle, the ship was dismasted so that the propulsive thrust remained entrusted only to the oars; the trireme was long, thin, light and with very little draft and it could easily be beached every evening.

This type of ship, with the addition of another inclined sail mast at the bow and two or more rows of oars, evolved into the *liburna* (100 AD). This model of ship was widely adopted by the Roman navy which used it for patrolling against piracy in the various provinces of the empire [9].

The ships and navigation techniques of the archaic Greek navy derived from the Phoenician naval knowledge of the second half of the 2nd millennium BC; they were substantially those described in the Homeric poems and remained unchanged for centuries. In this period, local agriculture had become so productive that, with the development of maritime trade, it allowed the foundation of new colonies on the southern coasts of the Mediterranean, particularly in North Africa.

Merchant ships were not as fast as triremes but could carry large cargoes of various types: grain, oil, wine; terracotta pots and glassware; textiles and jewelry; metal tools, millstones, and timber[7]. All this was made possible by the deep

[7] Among the various products of the trade activity, sea salt is not mentioned since all coastal populations were able to produce it independently but even if sometimes not in sufficient quantities. Another famous product of sea was *Tyrian purple* that the Phoenicians obtained from the murex, a sea snail that abounded in their coastal waters, rich in bromine, a necessary

knowledge that sailors had of sea and atmospheric currents.

The Etruscans, thanks to their availability of wood, were able to build large sailing ships that in battle, with the help of oars, could ram enemy ships. For this reason, the Greeks and Romans considered the Etruscans, as well as expert sailors and navigators, "pirates" and therefore they feared them especially when they crossed them off the western coasts of the Italian peninsula. The importance of maritime trade for the Etruscan economy is wide shown both by the artistic depictions of ships and by the models found in the tombs.

2.3 The routes

Ancient sailors, driven by the wind, cruised along straight sea routes to reach the various landing places; even in high sea crossings the basic principle was to follow the prevailing winds, which therefore influenced the main trade routes [26].

The prevailing north winds made navigation along the southern coast of the Mediterranean (North African coast) dangerous, as they pushed vessels against shoals and rocks. Navigation along the northern coasts, on the other hand, was certainly “simpler”, both due to the morphology of the coasts, where there were frequent daymarks that allowed pilots to orient themselves, and due to the presence of beaches and coves, where one could take refuge in the event of sudden storms that could occur even in summer [1]. In the Mediterranean there are few navigable sea areas without coastal landmarks, as it can be seen in the map in figure 1. The average speed of merchant vessels, depending on their type of construction, could be from 3 to 6 knots, therefore these ships could travel approximately 50 nautical miles a day, always sailing within sight of the coasts. The longest voyages, without coastal landmarks were the Ionian stretch from Greece to Sicily and from the west coast of Sardinia or Tunisia to the Balearic Islands [1].

Herodotus of Halicarnassus (ca. 484 BC - after 430 BC) and Thucydides (ca. 460 BC - after 404 BC) agreed in believing that the average speed of an ancient ship was 5-6 knots, and therefore, considering the stops due to bad weather, rest etc., for example, 15 days were needed to sail from Greece to Sicily. Herodotus wrote that longer voyages might require a winter stopover, with sailing continuing into the following season. He also pointed out that sailors were able to grow the wheat while they waited. For example, the voyage, of about 1600 nautical miles, from Tyre, the main city of Phoenicia to Cadir [8], the current Cadiz, an area rich in silver could take 90 days or more, in other words, an entire sailing season. In that case, the ship would unload and reload the goods while waiting for the return voyage, which would take place the following year [12].

Scholars have much debated what the actual routes the Phoenicians travelled. Assuming that Mediterranean currents have not changed from ancient times to the present, it seems likely that ancient sailors took advantage of the *long-distance currents* also used by modern sailors. Therefore, the route from Tyre to Cadiz would probably

element for the development of this mollusc. The richness of this element throughout the area has shown by the quantity of bromine in the Dead Sea waters, about 850 million tonnes [11].

[8] *Cadir* was the westernmost Phoenician city as it was on the Atlantic coast in southwestern Spain.

have been: north of Cyprus - the coast of Anatolia - Rhodes - Crete - Malta - Sicily - Sardinia - Balearic Islands, and along the coast of southern Spain to Cadiz. The return journey would have benefited from the current flowing back through the center of the Mediterranean, figure 2. This would give as possible the following routes: from Cadiz directly to Malta and then Phoenicia, or Balearic - Sardinia - Phoenicia, or Balearic - Carthage - Phoenicia. It is not surprising that in each of these strategic stopping points, the Phoenicians founded colonies which effectively prevented, for some centuries, trade from other cultures, such as the Greeks, who therefore frequented above all the western coast of the Italian peninsula, see figure 1 [12].

The Greek poet Hesiod (8^{th}-7^{th} century BC) stated that everything had to be done in its time, especially sailing; in *Works and days* [19] he wrote: [in winter] *If you ever get the urge for hard seafaring / When the Pleiades chased by gigantic Orion/ Fall into the misty sea, well forget it:/ All sorts of winds are whipping around then./ Too late to have a boat on the wine-colored water./ Work the earth then, remembering what I told you./ Haul your boat onto shore and pack stones;/ All around it, to keep off the wind's damp./ And pull the bilge-plug so rain won't rot the hull. /Stow all the gear and tackle of your sea-going craft/ Away in your house, tucking the sails neatly,/ And hang the polished rudder up in the smoke./ Then sit tight until the sailing season comes. (vv. 684-696)* […]/ *Fifty days after the solstice, toward the end/ of summer, the season of scorching heat,/ Comes the sailing season. (vv. 733-735)* […]/ *But the winds are easy to judge then/ And the sea's gentle. You can trust/ That swift ship of yours to the breeze/ Without a care, haul he down to the sea/ And load all your cargo./ But go as fast as you can and hurry/ Back home. Don't wait for new wine,/Or the autumn rains, or the stormy season coming on/ With high winds from the South* [Notos] *that stir up the sea. (vv. 740-749).* As seen in this passage, Hesiod underlines the importance of knowledge of meteorology for a "quite" navigation.

3. Meteorology for Mediterranean sailors

Navigation was carried out with wooden ships built in various lengths and widths with single or double propulsion, sails and rows. But in any case, the ships were unable to contrast the force of a stormy sea and therefore frequently sank if surprised by an adverse weather event, as evidenced by the hundreds of wrecks, from all historical periods, that are disseminated Mediterranean depths. It was therefore fundamental that sailors developed the ability to predict the weather. Knowing and guessing meteorological conditions was a critical part of the empirical-cognitive baggage of the ancient sailor-pilot, who had to develop a total perception of the marine environment to interpret meteorological signals [26].

For example, in the Strait of Gibraltar (figures 1), an essential gateway to exit the Mediterranean, the currents supported by the impetuous Vendaval, which blows from the Atlantic to the Balearic Islands, often forced ships not to risk crossing the strait for several days. The sailors awaited the attenuation of the Vendaval or the contrast to this by the Levant wind, which blows in the strait in the opposite direction to the first. With lack of winds, the strait of Gibraltar could remain at the mercy of the fog, equally dangerous for navigation. In any case, navigation either along the coasts or in the open sea, or by day or by night, had to begin and continue with clear atmospheres and fair skies. For ancient sailors, however, before setting out to sea and during navigation, it was critical to know the "sea bulletin" that the deities communicated to seafarers through precursory signs of meteorological events, entrusted to the stars and animals inhabited the sea waters and the marine skies. The second book of *La Nautica* [5] is significant on these aspects.

Below are some examples of events that ancient navigators believed to be premonitory *signs* of meteorological events linked to the state of the sea. These examples are taken from Greek, Roman and Byzantine authors, in particular the Roman ones who had most developed and codified the *theory of signs*.

The coupling of Lightning and Thunder as a sign of atmospheric forecasting is attested by Aratus of Soli (315 BC - 240 BC), Theophrastus of Eresus (371/370 BC - 288/286 BC), Pliny the Elder (23 AD - 79 AD), and it is considered a sign even today. Aratus stated: *If lightning springs from all points of space, from the harsh regions of Eurus, from the regions of Notus, from the peaceful domain of Zephyr, and from the frozen sky of Bistonia* [ancient Greek town near Vistonida lake], *the sea will be rough without end or measure by a multitude of storms* [4].

In reference to the Moon, Virgil (Publius Vergilius Maro 70 BC - 19 BC) stated in the Book One of *Georgics*: […] *But if on her fourth night's rising – for this is the sign most sure –/ Through the heaven with horns unblunted she rides in radiance pure./ Then all that day, and its offspring that follow in its train/ On to the end of lie month, shall be free from wind and from rain:/ And the shipmen, from peril delivered, shall pay their vows by the sea/ Unto Glaucus, to Ino's son Melicerta, and Panope*[9]. […][24], (*Liber I*, vv. 432- 437 [34]). Again regarding the horns of the Moon, as Pliny the Elder wrote (Liber XVIII, 348 [28]), Marcus Terentius Varro (116 BC - 27 BC) stated that […] *If on the fourth day of the moon her horns are upright, this will pre-sage a great storm at sea, unless she has a circlet round her, and that circlet unblemished, since that is the way in which she show, that there will not be stormy weather before full moon* [28]. Other meteorological signs given by the Moon are specified in the second book of [5], vv. 420-439.

Clouds are meteors that, rather than indicating the weather, signaled (and still do) the presence of islands not visible from the ship, even on clear days, because they were too far away. In this case, *God willing*, a small, isolated cloud was (and still is) formed above the island. In the Mediterranean, an example is the island of Montecristo, which is not visible in stretches of sea between Sardinia and Tuscany. Obviously, this phenomenon is not due to a divine action, but it is caused by the rise of the air, along the rocky walls of the island (about 600 m), which cools down causing the vapor to condense into a small and localized "signal" cloud.

Regarding the Sun, Virgil stated in the Book One of the *Georgics* [34] that the Sun will give very specific meteorological signals: *This too shall it profit yet more to remember—when now from the sky/ He* [The Sun] *sinks, having traversed his course, full oftentimes then we espy/ Over the face of the sun the changeful colours trail./ Sea-green giveth warning of rain, flame-red of an easterly gale* [Euros in

[9] Glaucus, Melicerta and Panope were three marine deities who protected navigation.

latin]/ *But if on his ruddy fire dark spots shall begin to lie./ One seething fury of wind and cloud shall be earth and sky./ Let no man counsel me on a night like that from the land/ To laimch on the deep, nor to pluck from the shore the hawser-band!* [24], (*Liber I* vv. 450-457 [34]). Other meteorological signs given by the Sun are found in the second book of [5], vv. 386-419.

Even the Stars, the *minutest lights* of the night sky, inform us about the weather; in the second book of *La Nautica* [5] the verses 443-470 tell us that: the Night sometimes feels pity for sailors who are lost among the waves, and through the stars tells them how to act. If the Night shows you the stars, of the Ara[10] constellation, without clouds and the rest of the sky is covered by a light veil of fog, return quickly to port; if you don't do it, you will beat mercy of the sea you challenged. But if the stars on the humerus of the Centaurus[10] constellation are a little covered by clouds and the stars of Ara are bright, there is no need to fear the south wind, Ostro, but Eurus (the wind born in Aurora's kingdom) will come to your aid. There is a sign of the wrath of the sky even when the stars little by little lose brightness, and if, when the shadows envelop the earth, a star is seen falling in a long and glittering path, from that direction will come the untimely assault of proud winds.

But the surest predictors were the birds which, with their flight, were closest to the deities and were, therefore, considered their privileged messengers**.** In general: the disorderly flight of birds accompanied by screeching was a sign of a storm for sailors; the rapid flight from the sea to the land, or the gathering near the swamps and the banks of the rivers, or the appearance of many white birds in unusual places, were precursory signs of bad weather; on the other hand, the flight of birds scattered or in small groups was an indication of good weather.

The deities also used terrestrial animals to send meteorological information to human beings, but certainly not to seafarers for whom the signs shown by sea animals were more significant.

We briefly show the *meteorological specificities* of some birds and other marine animals; for the connections between some of these birds and the celestial and terrestrial divinities, see [5], second book, vv. 471-524.

- *Heron:* the disorderly flights and screeches of this migratory bird, which lives in the swamps, were a sign of a storm. Theophrastus wrote: *It is a sign of wind or rain when a heron utters his note at early morning: if, as he flies towards the sea, he utters his*

[10] The Greek astronomer Claudius Ptolemy (ca. 100 – ca. 168 AD) compiled a catalog of 48 constellations (of the 88 registered today) also observable from middle latitudes. The position of the constellations, relative to the Earth, has changed over time due to the precession of the equinoxes. In fact, some constellations, easily visible in antiquity, are today poorly visible from the northern hemisphere. Among these, we remember:
- *Ara*, (in Latin: The Altar), is a small constellation of the southern sky, visible near the tail of Scorpius. From northern hemisphere it is possible to see its main stars, but only from latitudes lower than 30° N.
- *Centaurus* it is one of the brightest and largest constellations in the sky and is visible in its entirety from the southern hemisphere or at low northern latitudes. In historical times this constellation was entirely observable even from middle latitudes.

cry, it is a sign of rain rather than of wind, and in general, if he makes a loud cry, it portends wind. (*Concerning Weather Signs* 18-21, [32]). Aratus considered the disorderly flights and the shouting of these birds when they fly from the sea towards the land to be a sign of storm. Furthermore, he considered the high-pitched voices of the heron and its rapid flights from the land towards the sea to be an omen of bad weather [23]. Callimachus of Cyrene (ca 310 BC – ca 240 BC) affirmed the quiet flights of the heron from the sea towards mainland were a harbinger of good weather [23].

• *Halcyons*: Virgil, evidently echoing a popular opinion about weather forecast, stated that when this sea bird, dear to Thetis, understands that the weather will be good it does not expand its wings to sun itself on the leeward beaches, while the opposite is evident when bad weather is forecast [34].

• *Swan:* Isidore of Seville (560 - 636) preserved in his works many beliefs of his contemporaries, and regarding this bird sacred to Apollo, he wrote that *Sailors say that this bird makes a good omen for them* [22], [23].

• *Coot and gull:* Theophrastus wrote *It is a sign of rain when these birds plunge under water, a sign of wind when they flap their wings.* (*Concerning Weather Signs* 26-29 [32]). Pliny stated that the voracious gulls flee from the sea or ponds when they foresee wind. According to Marcus Tullius Cicero (106 BC - 43 BC): *Grey coot in fleeing the raging abyss of the ocean, /Utter their warnings, discordant and wild, from tremulous gullets, /Shrilly proclaiming that storms are impending and laden with terrors* (Liber I, 8 [13]). Virgil, Pliny, Rufius Festus Avienius (4th century AD), Isidore of Seville also tell us about this bird.

• *Waterhen:* according to Theophrastus it is a sign of rain when this bird, or other waterfowls, flap their wings on the water of a lake or sea (*Concerning Weather Signs*, 18 [32]).

• *Goosander:* seafarers consider the frequent fluttering of this aquatic bird, its cries, its numerous dives into the water, as a harbinger of strong winds or storms. Theophrastus stated that the flight of this bird during a calm, it is a sign of coming wind [32]. According to Isidore of Seville, goosanders, when they foresee unfavourable weather, fly, with great clamour, towards the coast [23]. These popular beliefs are later reported also by several other Latin writers.

• *Dolphin:* sailors considered the frequent leaps over the sea of this beloved fellow traveler as a sign of future bad weather. According to Theophrastus, a dolphin diving near the coast and reappearing often indicated rain or storm. Plinius the Elder stated *for instance dolphins sporting in a calm sea prophesy wind from the quarter from which they come, and likewise when splashing the water in a billowy sea they also presage calm weather.* ([28], Liber XVIII). Marcus Annaeus Lucanus (39 AD - 65 AD), Isidore of Seville, Flavius Aurelius Cassiodorus (c. 485-490 - c. 580), Cicero and others also mentioned the prediction of storms from the jumps of dolphins. Even Dante Alighieri (1265 - 1321) mentioned dolphins as harbingers of sea storms: *Even as the dolphins, when they make a sign / To mariners by arching of the back, / That they should counsel take to save their vessel* (*Inferno* XXII vv. 19-21, [3]).

• *Crab and shells;* sea and freshwater crabs, and seashells have the property of predicting the weather, as reported by Pliny [28]. The sea crab comes out the sea to avoid being dragged away by the waves and the freshwater crab abandons the banks of the river or stream for fear of being swept away by the current. Finally, seashells cling to underwater rock cavities to escape the forthcoming storm [28].

• *Pilot fish*[11]*;* Oppian of Anazarbus (2nd century AD) stated the presence of this pilot fish near ships was considered a harbinger of calm sea [27]. Claudius Aelianus (c. 175 – c. 235 AD) added that these fish warn sailors of the proximity of dry land, when it is not yet possible to distinguish it with the naked eye: [...] *when vessels are cleaving the mid-ocean these Pilot- fish swim up as though they were in love with them and attend them like a bodyguard, circling this way and that as they gambol and leap.[...] Thereupon those in control of the vessel know that they must look around for land, not because they judge by beacons but because they have been instructed by the aforesaid fish*. (Book 2, 15 [2]).

• *Octopus, squid, cuttlefish;* these marine animals can predict any change in the weather in order to take any timely action for their survival. When a storm is imminent, the squid appears most often at the sea surface and is seen continually jumping out of it. In order not to be swept away, the cuttlefish grabs the shallows of the sea depths with its tentacles. Various Greek and Latin authors talked about the prognosticating ability of the octopus, as B. Baldi wrote in his didactic poem *La Nautica*": *when the sky has a hoarse voice, the octopus leaves the bottom and rises to shore where, with its tenacious arms, it firmly holds on to the roundabouts and small stones* (Book 2nd, vv. 492-495 [5]). Theophrastus, Plutarch, Pliny and Cicero also wrote about the aforementioned movements in the imminence of storms, and about the related popular beliefs.

• *Sea-urchin;* this echinoderm can foresee gales a day or two in advance. Many authors talk about this characteristic, Plutarch, Aelian, Cassiodorus etc. We can summarize their thinking with Pliny's words: *It is said that they can forecast a rough sea and that they take the precaution of clutching stones and steadying their mobility by the weight: they do not want to wear away their spines by rolling about. When sailors see them doing this, they at once secure their vessels with more anchors.* ([29], Liber IX).

• *Black wing flyingfish* (*Hirundichthys rondoletii*); this small fish is equipped with wings that allow it to fly on the sea surface and it has a great ability to immediately foresee any change in weather. The ancients considered it as a harbinger of a storm because they were convinced that it flew out of the water to escape the imminent storms. As mentioned above, similar behaviour was attributed to squid. This popular belief is also confirmed by Pliny [28], Marcus Manilius (1st century BC-1st century AD) and Isidore of Seville.

• *Sea sponges and jellyfishes;* like the previous ones mentioned, these animals also can foresee changes in the weather. The sponges fold back on themselves to avoid being torn away from the seabed by the water vortices. The jellyfishes, predicting gales, appear in enormous quantities and flee towards calm areas [28], [32].

[11] The ancient Greeks called this fish *Pompilos*, from the name of sailor who saved the nymph *Okyroe* from Apollo who, in revenge, transformed him into pilot fish.

4. Conclusions

Navigation of the seas and oceans was attested […] *Human beings managed to reach Australia from Southeast Asia some forty to sixty thousand years ago* […]; and then expanded into the habitable islands of the "vast" Pacific Ocean, after about thirty thousand years [14]. Obviously, the ancient peoples of the Mediterranean basin also practiced navigation on this "small" sea; as highlighted by the numerous archaeological evidence, in reference to the cultures analyzed by us. The first written information dates back to Homer's *Odyssey* (around 800 BC), which tells about Odysseus and his journey home after the Trojan War; the date of the events is uncertain, but it is likely to be between 1334 BC, according to Duris of Samos (ca. 340 BC - ca. 270 BC) and 1184 BC, according to Eratosthenes of Cyrene (ca. 276 BC - ca.194 BC).

This work presents a time interval of about a thousand years, very limited compared to the history of navigation, and an equally limited space, the only Mediterranean Sea, compared to the breadth of oceanic navigation. Limited time and space, however, show frenetic naval activity both along the coasts and in the open sea. The latter was made possible by the sailors' deep knowledge of marine and atmospheric currents in terms of reliability of both direction and intensity.

In summary, we can say that the Mediterranean with its ships, for centuries, was the main center of trade, enormously exceeding, in terms of quantity and variety of goods, the land transport which went from the coastal countries to those in the interior. This primacy fell from the beginning of the modern age when the Atlantic trade routes were defined through the systematic study of the winds [14].

Sailors based weather forecasts on more imaginative, but less reliable, knowledge. However, already with the first studies of atmospheric conditions, meteorological phenomena rapidly lost their aspect of "prodigy" and only some, for which an explanation had not been reached, remained within the scope of divinatory interpretation.

Virgil in *Georgics* (1, 415-423 [34]), referring to the predictions made by animals, denies the doctrine of the Pythagoreans and Stoics, which attributed to animals a spiritual gift infused by divine care or a foreknowledge of things granted to them by Fate. He attributes the behaviour of animals to physical causes, variations in humidity and temperature, movement of clouds due to the wind, etc., clearly visible signs of meteorological changes that man himself could interpret without their help [7].

However, we had to wait until the 17th century for the beginning of a new era, in which the Galilean method affirmed the primacy of experimental measurements over apodictic deductions, linked above all to the physical conceptions of Aristotle (384 BC - 322 BC). It was with Evangelista Torricelli (1608 - 1647) that, with the experimental discovery of atmospheric pressure (1644), the foundations of modern meteorology were laid [7].

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THE HISTORIC LIGHTHOUSES OF THE ITALIAN COASTS

Fabrizio Beninicasa, Matteo De Vincenzi, Gianni Fasano

Abstract: The tall tower building with an intense light source on the top, visible far away, called a lighthouse in English, takes its name in the Romance languages of *faro*. The fuels used to produce lighting have progressively adapted to the times: bundles of dry wood, olive oil, wax candles, sperm whale fat, paraffin oil, acetylene, arriving to electricity. The lighthouses didn't only have positive aspects; in fact, they not only facilitated bearings during night navigation, but also indicated to the pirates the coastal towns to plunder. This gave rise to a kind of "land piracy" since "prankster" characters lit "fake beacons" on reefs, shoals, etc. waters where ships stranded and were therefore more easily plundered.

This paper shows the current number of lighthouses in Italy, giving greater emphasis to the Italian historic lighthouses, which, by definition, are those that meet at least three of the characteristics established by IALA. As in other European nations, also in Italy the lighthouse lantern was often placed on the top of the bell towers of the churches along the coastline. The oldest Italian lighthouses are on the Tyrrhenian coast the lighthouse of Rome Port and on the Adriatic coast the lighthouse of Ravenna Port.

Obviously, we will only mention the lighthouses, which in our opinion are the most important and given the historicity of these we will only deal with the "bright" lighthouses, outlining the historical-geographical context within which they were built.

Keywords: Ancient lighthouses Navigation; Ancient Meteorology; Sailing techniques.

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Fabrizio Beninicasa, Matteo De Vincenzi, Gianni Fasano, *The Historic Lighthouses of the Italian Coasts*, pp. 557-572, DOI: 10.36253/979-12-215-0556-6.49

1. Introduction

Virgil[1] and Ovid[2] trace the origin of the lighthouse to the myth of the secret lovers Hero and Leander; myth also remembered by Francesco Petrarca[3]. Leander, a young man from Abydos, was the lover of a young priestess of Aphrodite, called Hero, who lived in Sestos, a city located on the other bank of the Hellespont, opposite Abydos, about 1350 meters away from it. (fig. 1). Every night Leander swam across the strait, guided by the light of a lamp that Hero lit at the top of the tower of his house. On a stormy night the lamp was extinguished, and Leander, in the darkness, lost his way, could not find the coast, and drowned. The next day Hero saw Leander's corpse that the sea had thrown at the foot of the tower, and, not wanting to survive her lover, she jumped to her death from the tower [15]. The myth of Hero and Leander is the first representation of the light of *fire that guides those traveling by sea in the darkness of the night* [25].

In ancient times, navigation was mainly coastal and diurnal but then human beings also learned to navigate at night by orienting themself with the stars; but this was not enough to avoid shallow waters, rocks, sandbanks, etc.[4] Thus, the first lighthouses were born, i.e. beacons made by wood stacked and lit in critical places to signal danger along the route to sailors.

Figure 1 – On left Stretch of sea, approximately 1350 m long, between Abydos and Sestos that Leander swam across every night to reach Hero (Graphic elaboration of G. Fasano from [101]). At right Hero drowned, lying on the beach (etching, print maker: J. van de Velde (II), after design by: W. P. Buytewech, 1621) [102].

[1] Virgil (Publius Vergilius Maro 70 - 19 BC) Third Book of *Georgics* (vv. 219-282) [39].

[2] Ovid (Publius Ovidius Naso 43 BC - ca 18 AD) in *Heroides* epistle XVIII (Leander to Hero) and epistle XIX (Hero to Leander) [27].

[3] Francesco Petrarca (1304 - 1374) in *Trionfi - Trionfo dell'amore* (in english *Triumphs-Triumph of Love*) chap. III vv. 19-21 "*Altra fede, altro amor: vedi Ipermestra, / Vedi Piramo e Tisbe inseme a l'ombra, / Leandro in mare et Ero a la finestra.*" (*See Hypermnestra, faithful in hernlove;/ See Pyramus and Thisbe in the shade, / Leander swimming, Hero at window.*) [28], [29].

[4] For other problems that arose during navigation, see [4].

The darkness posed a mortal danger, so bonfires had to be fuelled with fuel that produced a bright flame. For this purpose, dry bunches of erica or broom were preferably used. Probably for such a burdensome task slaves or prisoners were employed [25].

Over time, special metal containers were created which, with burning wood inside, could be lifted from the ground using ropes and pulleys to make them more visible, becoming real daymarks[5], to which Homer compares Achilles' shield: [Achilles] *he took the shield, / Massive and broad, whose brightness streamed as far / As the moon's rays. And as at sea the light / Of beacon, blazing in some lonely spot / By night, upon a mountain summit, shines / To mariners whom the tempest's force has driven / Far from their friends across the fishy deep* (*Iliad* book XIX vv.450-456 [16]).

But if the lighthouses, on the one hand, facilitated the bearings of the sailors during night navigation, on the other they also indicated to the pirates the coastal cities to plunder, along routes still unknown to them. This stimulated the creativity of "land pirates" who lit "false lighthouses" on reefs, shoals, rocks, beaches, and shallow waters where ships got stranded and thus became easy prey [2] [24].

Figure 2 – Brazier for signalling shoals, rocks, shallow waters, etc.

During the Roman Empire, the first stone towers were built on top of which fire was lit. In order to distinguish their fires from the deceptive ones visible on the coast, the braziers were equipped with perforated metal domes so as to make the univocal radiated light signal [3] (fig. 2). As reported by Pliny the Elder (23-79 AD) in *Naturalis historia* (Liber 36, 18) [31], the inhabitants of the islet of Pháros in front of Alexandria, Egypt, lit bonfires at night to signal the presence of their island. and to increase the light intensity, since 650 BC, they used burning mirrors[6] [3].

The name of the island probably derives from the word *phanós* (torch in ancient Greek) assonant to *pháros*, considering the customs of its inhabitants. Precisely on this island in the 3rd century BC. an imposing tower structure was built for light signalling, which was called "Pharos" like the island. The Pharos of Alexandria was damaged and renovated several times until the earthquakes of 1302 and 1323 destroyed it definitively. Its everlasting memory remains in the name that all Greek Latin languages give to this type of building (*faro*, in Italian and Spanish, *phare* in French, *farol* in Portuguese), while Anglo-Saxon countries call it lighthouse (house of light) and the Germanic *leuchtturm* (lantern tower).

One of the problems of lighthouses has always been how to produce lighting: after wood, both natural and impregnated with resins, coal was used, which however did not provide a sufficiently bright light. In both cases, atmospheric events, wind

[5] Daymarks are all those natural and artificial elements of remarkable size and height which have characteristics clearly visible and recognizable from the sea. For example, daymarks are mountains, promontories, buildings along the coast (towers, lighthouses, bell towers, etc.).

[6] Burning mirrors are parabolic mirrors that concentrate light radiation into a beam, which reaches them from various ways; this radiation, thus intensified, is projected in a predetermined direction.

and rain, could interfere negatively. Therefore, around 1200, it was thought to protect the flame with a glass lantern. This solved some problems but introduced others: for example, the need for continuous cleaning of the glass. Other fuels were experimented with the lantern: olive oil, wax candles, sperm whale fat[7], paraffin oil, acetylene, etc. The electrification of lanterns began only between the late 1800s and early 1900s. For a detailed history of the evolution of lighthouses, see [2], [24].

There are currently around 20000 active lighthouses in the world. There are 147 lighthouses located along the 800 km of Italian coastline [23]. Over time, due to the structural and functional differences in *light signalling devices*[8], it has become necessary not to use the term lighthouse for everyone, but to specify the nature of the device depending on whether it can be a lighthouse or a beacon. On the Italian coasts there are 727 lights, (including daybeacons[9] and buoys) [23]. These terms have a sub-classification established by *International Association of Lighthouse Authorities* (IALA-AISM) [17] [103]; for a summary on this aspect, please refer to [3] where there are listed the national and international institutions that defined them.

These terms have a subclassification that defines historic structures as those that meet at least three of the following characteristics established by the IALA-AISM:

- the station has been designed to be manned,
- the range of the light should be greater than 15 nautical miles and the height of the tower should be greater than 10 m above the ground,
- historic architectural interest (design, use of material, etc.),
- the station is over 100 years old,
- the station is protected by the local Cultural Heritage Authority,
- Archaeological importance.

As regards this class of signalling structures, we will limit ourselves to showing the historical and geographical context within which the lighthouses were built, which we consider more significant due to their very "complex" history or the very "particular" environments in which they were located.

2. The Italian Lighthouses

The first maritime signalling devices, with or without lighting, date back to the Phoenicians between 1200 and 300 BC. The Greeks and Romans inherited this

[7] The sperm whale (*Physeter macrocephalus*) is a large marine cetacean (the mature male can reach 26 m and weigh 50 tonnes). The head is enormous and contains, in a cavity above the jaw, an oily and transparent substance called spermaceti (in the past it was believed to be the sperm of the cetacean). The sperm whale, a cosmopolitan species also present in the Mediterranean, was hunted for its fat, meat, spermaceti and ambergris. The latter is produced by the animal's digestive system and was used in ancient pharmacopoeia and in the production of perfumes.

[8] The clarification is due since there are signalling systems that do not use light; see footnotes 9 about *daybeacon* and 19 about *radio beacon*.

[9] Daybeacon is an unlighted fixed signal emerging from the sea, of various shapes (small triangles and small squares) and materials. It is placed to signal to sailors both particularly dangerous points, such as rocks, shoals, etc., and reference points for the landing of boats and for their entry into the port access channels [6].

tradition and built numerous lighthouses in the Mediterranean.

With the fall of the Western Roman Empire (5^{th} century) there was a clear reduction in navigation, a block in the construction of lighthouses and the progressive abandonment of existing structures. This also was due from the need to hide the ports accesses to limit the Barbary incursions. Signalling with lighthouses was abandoned and the use of beacons on the hills returned. New lighthouses were built only starting from the 11^{th} century, with the development of the Maritime Republics, in particular Genoa and Pisa [3], and the resumption of maritime trade, such as the reconstruction of the Tower of Genoa, the lighthouse of Porto Pisano (Livorno), the Tower of Capo Peloro (Messina). Furthermore, as later happened in other countries, lanterns were placed on top of the bell towers of coastal churches. Probably no country in the world has more ancient lighthouses than Italy. Over time the light signalling systems have been modernized, but most of the structures were built totally or partially between the 1200s and 1300s [2].

In figure 3, the lighthouses described (in roughly chronological order) in this work[10] are indicated with a blue symbol while the lighthouses, mentioned but not described, are indicated with a red symbol. The latter define the geographical limits

Figure 3 – Map of Italy with the "current" regions and lighthouses described in the text (blue) and the "extreme" ones (red).

[10] The lighthouses are listed by writing in italics the historical name of the location at the time of their construction; the current name and the Italian region in which it is located are indicated in brackets.

within which there are, or were, lighthouses. We can observe that all the lighthouses are enclosed in the rectangle between the latitude 45° 40' N on which the lighthouse of Trieste (Friuli Venezia Giulia), the northernmost, is located, and the latitude 35° 31' N of the lighthouse of Lampedusa Island (Sicily), the southernmost.

The other two sides of the rectangle are the meridian passing through the *Punta Palascìa* lighthouse (Capo d'Otranto, Apulia), longitude 18° 31' E, the easternmost, which sees the sun rise first; and the meridian of the *Capo dell'Arma* lighthouse, in *Capo Verde* (in Liguria between San Remo and Imperia), longitude 7° 50' E, the westernmost. As regards the *"saying good night to the Sun"* in the West, the situation is more complex than the *"saying good morning to the Sun"* that is given in the East.

The lighthouse of Capo Caccia (Sardinia) has a longitude (8° 10' E) slightly higher (i.e. further east) than that of Capo Verde (7° 50' E) but it is also much further south (latitude 40° 34' N versus 43° 49' N of Capo Verde). All this means that Capo Verde is the last lighthouse to see the sunset in the spring - summer period (specifically from mid-March to mid-September) when in the north the days are longer. In the rest of the year the days are shorter in the north than in the south and therefore Capo Caccia, although slightly further east than Capo Verde, is able to see the sun for longer than the other place.

In summary, to quantify the phenomenon, we can say that at the Summer Solstice the daytime length in Cape Verde is approximately 12 minutes longer, while at the Winter Solstice the daytime length n Capo Caccia is approximately 9 minutes longer more. compared to the other lighthouse. For more information on procedures for calculating daytime length, see [5].

2.1 Ancient Lighthouses in Roman period

Messana (Messina - Sicily)

The lighthouse was about 14 km from the city on the Peloro Cape promontory; it is shown on the coins of the Proconsul of Sicily Sextus Pompeius Magnus Pius (fig. 4).

Figure 4 – Sextus Pompeius Denarius with on the obverse the *Messana Pharos* (Messina lighthouse) adorned with a statue of Neptune placed on a trireme with *aquila* (eagle in Latin), sceptre and trident, and the legend MAG PIUS IMP ITER (Magnus Pius emperor for the second time); on the reverse the Scylla sea and the legend PRAEF CLAS AT ORAE MARIT EX SC (Prefect of the Fleet and the Maritime Coast by Decree of the Senate) [104].

The lighthouse was built in 40 - 39 BC to replace a previous signal tower on Peloro Cape and a similar one on the opposite side of the Strait. Strabo (before 60 BC - 20 AD ca) wrote in *Geographica* (in english Geography) […] *it was a custom in early times to set up landmarks like that. For instance, the people of Rhegium* [Reggio Calabria] *set up the column—a sort of small tower—which stands at the strait; and opposite this column there stands what is called the Tower of Pelorus* […]. ([32] 3, 5, 5). Among his activities, Sextus Pompeius also carried out piracy which allowed him to "control" merchant ships transiting the Strait of Messina.

Capreae (Capri - Campania)

The Roman lighthouse of Capri, on Mount Tiberius, was built by the Emperor Tiberius next to his villa (*Villa Jovis)*. The structure was used not only as a lighthouse, also for light signallings (also done with mirrors) to communicate with the military outpost of Punta Campanella (Sorrento Peninsula) and, through this, with Cape Miseno, in the Gulf of Pozzuoli. From here the messengers on horseback, reached Capua thought *via Campana* and then, traveling along the *via Appia* (Appian way), arrived in Rome where they communicated Tiberius' orders, or, with the opposite route, brought the "latest news" to Tiberius. In this way the emperor, while remaining in his splendid villa, was always in contact with the capital of the Empire. Unfortunately, as Suetonius (ca 69 - after 122 AD) wrote in *De vita Caesarum* ([32], liber III, 74) *A few days before his* [Tiberius] *death the lighthouse at Capreae was wrecked by an earthquake* in 37 AD. Emperor Domitian (51 - 96 AD) restored the lighthouse between 91 and 96 and it continued to function until the 17th century.

Puteoli (Pozzuoli - Campania)

It was a centre of the *Campi Flegrei* (Phlegraean Fields) of greatest importance. In the Roman period the city became, for political, military, and commercial reasons, one of the main ports of the Lower Tyrrhenian Sea, equipped with a lighthouse, built Octavian Augustus epoch. The lighthouse may have been destroyed by an earthquake and dragged into deeper water. In fact, there are several written references in the classical literature to a lighthouse on the end of the mole [20] [35] The Puteoli port, for several years, was the sea base for Roman expansion in the East, but its fortune began to decline both with the establishment of the port of Ostia, at the mouth of the Tiber and because of the problems of silting due to the bradyseism [21]. Despite this, the port continued to be, until the end of the empire, the main port structure in Campania as evidenced by important archaeological remains [21].

Ravenna (Emilia-Romagna)

The first settlement, of what was a lagoon site with direct contact with the sea, was very probably Etruscan (5th century BC) and subsequently Umbrian. In the 3rd century BC. it obtained the status of federated city from the Romans and in the 1st century BC. the inhabitants obtained Roman citizenship. Octavian Augustus established near Ravenna, the home port of naval fleet that was to control the eastern Mediterranean. The choice was suggested by the ease of both connections and supplies towards the hinterland, via the *Via Popilia* (North), and exchanges between sea and land, via river-lagoon routes on which large basins opened up suitable for the shelter of ships. The chosen place (about 4 km south of the town) took the name of Classe (from the Latin *clăssis* = fleet) and developed with impressive urban and productive structures that promoted the economy of the hinterland. The development of Classe continued in the 2nd and 3rd centuries but then the town began to decline due to the unstoppable siltation of the port channel, into which river waters laden with alluvial debris flowed. The abandonment of Classe was a consequence of its economic decline, which also led to the destruction of the buildings to recover the construction material.

Pliny the Elder noted in *Naturalis Historia* (Liber 36, 18) [31] about the importance of Ravenna lighthouse (the first in the Adriatic) that compared for relevance to Alexandria Pharos [14]. A mosaic, in the *Basilica of Sant'Apollinare Nuovo* (6th century AD) in Ravenna, for some scholars, attest to the existence of a lighthouse in the port of Classe. It is not known where exactly the lighthouse was sited although various hypotheses have been made about its location and various studies are underway [14] [20] [37]. Archaeological excavations conducted in the 2000s have identified, near the mausoleum of Theodoric north of Ravenna, another lighthouse built in late ancient times [12] [14].

The decline of Ravenna also began in the 9th century; the branches of the Po that descended to Ravenna dried up due to the shift north of the Po axis; the still waters besieged the city, the coastline was moving away (in the 11th century it was already 3 km from the walls) the port capacity was miserably reduced; the functional crisis of Ravenna deprived it of its primary role of connection with East [13].

Portus - Port of Ostia (Latium)

The most important lighthouse in the Tyrrhenian Sea, documented in some way, is that of the *Portus Romae* (in english Port of Rome), built in 50 AD by Emperor Claudius (10 BC – 54 AD). It is depicted in a mosaic of the Baths of Ostia Antica and is described by Suetonius in *Vita Divi Claudi, ch 20* [34]: […] *He* [Claudius] *constructed the harbour at Ostia by building curving breakwaters on the right and left, while before the entrance he placed a mole in deep water. To give this mole a firmer foundation, he first sank the ship in which the great obelisk had been brought from Egypt, and then securing it by piles, built upon it a very lofty tower after the model of the Pharos at Alexandria, to be lighted at night and guide the course of ships*. In other words, it was created an islet where the lighthouse was built[11]. The works were completed during the reign of Nero and the port complex was called *Portus Augustus Ostiensis* [19] [20]. The name Ostia derives from the Latin term *ostium* (river mouth) in reference to the mouth of the Tiber, which once lapped the city before flowing into the then much closer Tyrrhenian Sea; in 1575 a flood shifted the course of the river, causing it to bend northwards. The excavations of the ancient city, probably commissioned by Ancus Marcius (7th century BC), have brought to light a fortified citadel, the *căstrum*, with solid walls made of tuff blocks, dating back to the 4th century BC, which became a military and commercial port of

[11] Geoarchaeological investigations carried out at the beginning of this century seem to have identified the "islet" where Claudius' lighthouse was built [14].

great importance only in the time of Claudius. At the beginning of the 2nd century the port was enlarged by Trajan who built a more internal hexagonal basin and made it more sheltered from sea storms [14] [19] [20]. Ostia acquired growing importance in the first three centuries of the Roman Empire until obtaining administrative autonomy as *Portus Romae* with Constantine the Great at the beginning of the 4th century. In these centuries the lighthouse was mentioned with admiration by various writers such as Dio Cassius. With the barbarian invasions, the decline of Rome, neglect and depopulation reduced the city to imposing ruins; these too were destined to disappear due to the siltation caused by the advancement of the coast [8].

Centumcellae (Civitavecchia - Latium)

Ancient Roman artificial port founded in 106 AD. by Emperor Trajan and equipped with a lighthouse, in 120 by his successor Hadrian. The construction of this new port was due to the need to reduce the intensity of goods traffic in the port of Ostia and to overcome the silting problems of this port, due to the Tiber [14]. During the Roman empire the city prospered and expanded considerably, its port always remaining fully efficient. After the political-military events that followed the fall of the Western Roman Empire, the city was occupied by the Byzantines in the 6th century and was destroyed by the Saracens 828. This latter event forced the population to move to a new settlement in a safer place inland which was built by order of Pope Leo VII around 854 [26]. Once the Saracen threat ceased, the population returned to the ancient city on the sea in 889 to rebuild it, calling it *Civitas Vetula*, hence Civitavecchia, which in 1431 became part of the Papal State [2].

2.2 The Lighthouses after the first millennium

In Italy, lighthouses began to be restored and reconstructed from the 12th century, with the development of the Maritime Republics and the resumption of maritime trade, for example the reconstruction of the Tower of Genoa, the lighthouse of Portus Pisanus (Livorno), the Tower of Capo Peloro (Messina). This latter lighthouse of fundamental reference for the navigation of the Crusaders towards the Holy Land [18].

Genoa (*Liguria*)

Until the 10th -12th century, the current port area was a natural landing place, also used in Roman era. In 1128 the construction works began to realize the docks and the stocks for commercial activities. Among the first works we must obviously mention the lighthouse, called late *Lanterna*, which is still functioning today albeit with frequent maintenance and continuous structural and technological updates. It is not certain when the first tower was built (some sources report 1128 [1] others 1139 [14]), on the promontory of San Benigno, a place where light signals were already used for boats in ancient times. The Tower was slightly lower than the current one; at its top, beacons were lit fed by bundles of dry heather or broom stems. In 1326 (according to others from 1329) the first olive oil lantern was installed, whose light was concentrated in a beam thanks to transparent crystals produced by Ligurian and Venetian master glassmakers [1] [22]. The heavy structure of the lighthouse rests on the last remaining rock of the promontory of San Benigno, which was demolished to obtain the boulders necessary for the maritime works of the port. In 1513 during the clashes between the French army, which occupied Genoa, and the Genoese insurgents the lighthouse was irremediably damaged and remained so until 1543 when it was completely rebuilt with its 77 m high tower, making sure the lantern is located at 117 m above sea level [2].

Livorna (Livorno - Tuscany)

The site *Livorna*[12] located at the southern end of the Arno alluvial plain, is already mentioned as a hamlet of *Portus Pisanus* in a parchment manuscript from 1017. In 1150 the Pisans built a tower with a lighthouse, on the surfacing rocks of *Secche della Meloria* west of Livorno, to make navigation safer [14]. In 1163, the first light called the Torre del Magnale was built at the entrance to the port, which had the lantern at the top and the port commander's house at the bottom [14]. Near this there was a smaller tower while chain was stretched between the two to close the port. In 1286, two years after the battle of *Melori*a, the Genoese demolished the tower that signalled the *Secche*. After its destruction, in 1304 the Pisans built a lighthouse (designed probably by Giovanni di Nicola Pisano), about 300 m away from the port. It was consisted of two overlapping cylindrical (12 m in diameter) towers for a total height of 57 m including the lantern (figure 5) [36].

Francesco Petrarca also wrote about the monumentality of the Livorno lighthouse in *Itinerarium Syriacum* (1358) [30]: […] *et fere contiguum Liburnum, ubi prevalida turris est, cuius in vertice pernox flamma navigantibus tuti litoris signum prebet* […] (tr. *and almost adjoining with Livorno, where a very strong tower stands, on top of which in the night a flame shows sailors the safe coast*) [14] [36].

Figure 5 – Lighthouse of Livorno: build in 1304 destroyed in 1944, during the Second World War, but faithfully rebuilt in 1956.

After various changes of dominion, in 1421, the Port was sold to the Republic of Florence which chose it as its seaport. Within a century and a half, with the expansion of the port, the city of Livorno was also built from scratch (in particular with the advent of the Medici lordship). From there, by means of an artificial canal, it was able to transport the goods by means *navicelli*[13], from the Medici Port to Pisa and from here, navigation on the Arno River, to Florence. In 1423 the Florentine Republic had the *Torre del Marzocco*[14] built at the entrance to the port, so called due to the shape of the gilded

[12] For a study on the etymology of the toponym *Livorna* and its evolution in Livorno, see [10].
[13] The *Navicelli* were characteristic Tuscan boats of small dimensions, with a flat bottom, which were used for the river transport of goods.
[14] Marzocco is a heraldic lion, symbol of the Republic of Florence.

bronze weathervane placed on its top. The Torre del Marzocco was only a daymark clearly visible during the day while the light signalling was entrusted to the lighthouse. The lighthouse was destroyed in 1944, during the Second World War, but was faithfully rebuilt in 1956 [36].

Messina (Sicily)

In addition to the most famous roman lighthouse of Peloro Cape (see par. 2.1), the closest point in Sicily to the Peninsula, since 1557 there has been a second lighthouse on the Strait of Messina: *Torre della Lanterna* or *San Raineri* designed by Angelo da Montorsoli. The structure was built on the ruins of the monastery (13th century) dedicated to San Raineri, to allow the Spanish sovereigns to control traffic along the Messina coasts. A popular tradition has it that the hermit Raineri, a 12th century saint, lit bonfires at night to show the way to sailors. In some documents from the end of the 13th century it is reported that the Tower of San Raineri already existed, and bonfires were lit there as an aid to sailors; some friars took care of this [22] [105] [106].

Palermo (Sicily)

In June 1567 Carlo Aragona Tagliavia Prince of Castelvetrano, President[15] of the Kingdom of Sicily, laid the foundation stone for a new pier *Molo nuovo*, in the part of the *Tonnara di San Giorgio*. The new engineering work was called the *Molo d'Argento* (in Italian "Silver Pier"), due to its huge cost, and over the centuries it was equipped with further buildings and fortifications for its protection. In 1593 it was built a lighthouse, known as *Lanterna del Molo*, that was second only to that of Messina among the Sicilian lighthouses. In 1680 the *Lanterna* was equipped with batteries of cannons capable of firing broadsides at the surface of the water to hit opposing ships along the waterline. The port complex was so well fortified that it was practically impregnable from any attacks from the sea. The lighthouse remained active until 1943 when it was destroyed by Allied bombing during the Second World War [9] [11].

San Cataldo di Lecce (Apulia)

In Roman times the location (known as *Molo Adriano*, because for Pausania, it was built by the emperor Hadrian in 130 AD) was the port of the *Lupiae* colony, then became *Licea* and at present-day Lecce, about ten kilometres away, to which it was connected by a road [20]. The colony was also connected via the *Via Traiana* to the port of Brindisi, the main port on the Adriatic. Parts of a pier and a quay made of large stone blocks remain from the ancient Roman port; most of the remains were destroyed at the end of the 19th century for the construction of the quay of the new port of San Cataldo. The current structure of the small lighthouse (built in 1869) is typical of southern lighthouses [1] [23] [107].

[15] Viceroys of Sicily ruled the Kingdom of Sicily as the representative of the Aragon and Spanish Kings who acquired the title of King of Sicily from 1412 to 1713. The Viceroy could appoint a President of the Kingdom, i.e. a vicar performing viceregal functions in the event of impediment, prolonged absence or illness. The figure of Viceroy and President of the Kingdom remained active throughout the 18th century, when Sicily was under the House of Savoy, the Habsburg Monarchy of Austria and the House of Bourbons.

Portoferraio (Elba - Tuscany)

In the period 1778-89 the Grand Duke of Tuscany Pietro Leopoldo Habsburg-Lorraine had erected a tower with a lantern, 25 meters high, built on the northern bastion of *Forte Stella* (in Italian "Fort Star" built in 1540 - 1548 by the Medici, and so called due to its five-pointed plan). With the unification of Italy (1861), the lantern was adapted to new needs and the tower became one of the many lighthouses built on pre-existing fortifications [1].

Scoglio Mangiabarche (Sardinia)

The island of *Sant'Antioco* is connected to Sardinia by an artificial isthmus about 3 km long, probably built, by the Carthaginians and completed with a bridge by the Romans. The current port was built in 1936-38 and is equipped with a lighthouse; it is in the immediate vicinity of today's road route, which runs alongside the ruins of the Roman bridge. The main town (Sant'Antioco) on the island is 2 km from the port. Not too far from *Punta della Tonnara*, on the western coast of the island, detached from the island, is the rock *Scoglio Mangiabarche* (lit. "rock eats boats"). It is in a very dangerous stretch of sea due to the large number of outcropping rocks from which sailors, especially on stormy days, must keep well away; from this derives the toponym of the place. A small lighthouse has been active on this rock since 1935, one of the few not located on the mainland [1] [23].

Mal di Ventre Island (Oristano - Sardinia)

The island is a narrow and long granite rock, flat, with a surface of about 0,80 km^2, with a maximum length of 2 km and a maximum width of 1 km, with highest point, 18 m a.s.l. The name of the island, in Sardinian *Malu Ventu*, meaning "bad wind", became in italian *Mal di Ventre* (meaning stomach-ache) due to a very approximate translation by the Piedmontese cartographers of the Kingdom of Sardinia. But this name also represents the island well since, due to the strong Mistral winds, which blow for most of the year, the crossing from the Oristano coast to the island (about 9 km) is never very calm so much so that many sailors suffer seasickness. The island was already frequented in prehistoric times, as evidenced by a nuraghe on the beach facing Sardinia. Other ruins date back to the Punic and Roman periods. In the Middle Ages the island became a safe haven for Saracen pirates. Since 1955 there has been a lighthouse in the highest area of the Mal di Ventre Island; its tower brings the lantern to 26 m a. s. l. [23]. This lighthouse and *Scoglio Mangiabarche* one are not historical lighthouses in the strict sense, but since they are located on islets surrounded by large areas of outcropping rocks and, especially the latter, in the open sea, we have not considered the few years missing to make them centenary.

Aquileia-Grado (Friuli-Venezia Giulia)

We conclude this short list of lighthouses by mentioning a *non-lighthouse*. Aquileia city founded by the Romans in the 2nd century BC, which became a municipium in 89 BC, expanded in successive phases until it became a political-administrative centre. The city was also a rich emporium, thanks also to an important river port system, on the Natissa river, which connected it to the Grado lagoon; the seaport of Aquileia was located on the main island (Grado) of the lagoon, figure 6. No source mentions that there was a real lighthouse in the lagoon or in Aquileia, that is decidedly useless for indicating the more than one hundred islands and the countless outcropping rocks which were better identified with fires lit on low towers[16]. Some scholars have hypothesized the presence of at least one traffic signal tower at the mouth of the harbour given the importance of the Aquilia emporium and that its port hosts a detachment of the fleet (*classis*) of Ravenna [14]. Over time the fires on towers were replaced by day beacons[17]. Aquileia was repeatedly devastated by barbarians, but the fatal blow was given in 452 by Attila, king of the Huns, therefore the city was abandoned by the population who took refuge on the islands of the lagoon. It was the patriarchal seat until the Longabards invasion (568 AD) who chose Grado promoting it into a new port city [14]. At the beginning of the 11th century, attempts were made to give dignity and prestige to Aquileia but in fact it increasingly declined. In 1420 it was occupied by the Venetians. In 1509 it passed into the dominions of the Habsburgs of Austria whose events it followed, except for the Napoleonic period (1805 - 1815), until 1915.

Figure 6 – Map of the Grado and Marano lagoons. The *right route* towards Grado is indicated by a sequence of daybeacons (orange stars on the map) due to the presence of numerous shallow waters and outcropping rocks, that is impossible to signal with a lighthouse. The only lighthouse (purple star on map, since 1913) is in Lignano Sabbiadoro where it signals the narrow passage between Lignano and the Island of Marinetta; a passage that requires continuous maintenance to avoid silting up.

[16] For the aforementioned reasons there is currently no lighthouse in the lagoon. The island of Grado, in fact, is marked by a system of daybeacons 17 anchored to the seabed capable of oscillating and moving vertically, to keep the signal visible even with significant wave motion. Specifically, the daybeacon float is surmounted by a 5 m pole which supports both a light source, powered by a photovoltaic system for night-time signalling, and signboards. The latter are arranged to form conventional geometric figures, to indicate the type of danger and the path to take to avoid it. The other dangerous points present in the lagoon are highlighted with simpler structures.
[17] Daybeacon: any of various unlighted structures serving as a daytime aid to navigation. In other words, fixed signal emerging from the sea, of various shapes and materials, placed to signal to sailors both particularly dangerous points, such as rocks, shoals, etc., and reference points for the landing of boats and the entry of these into the canals access to ports.

Starting from the early Middle Ages, Grado, with its port, acquired considerable economic and commercial importance. From the 12th century, with the affirmation of Venice as the dominant centre of the Upper Adriatic the city began its slow decline until it was reduced to a minor hamlet and became definitely part of the Serenissima, whose fate it followed until 1797.

3. Conclusions

It is quite clear that this review is a short significative representation of the coastal Italian historic lighthouses: there are many more important ones, there are both in perfect activity and in "Eternal Rest"; there are refurbished ones in their specific function and other used for completely different purposes. With reference to this last aspect, many lighthouses are that due to their location, architecture, and history have been transformed into museums, tourist attractions, or worse, resorts for wealthy tourists.

In this work we wanted to highlight how lighthouses, from mere beacons, purely functional to signal dangers to sailors, over time, while maintaining this function, they have evolved into buildings to which often, in ancient times, it was associated the symbol or statue of a protector deity, in which during navigation rely on. Therefore, it came the architectural and artistic development of the towers and lighthouse lanterns. On these aspects there is a boundless world literature. We have pointed out to some less conspicuous ones that for geographical and historical reasons have performed their task and that today is codified by navies all over the world who tell us: *the function of lighthouses is to signal dangerous areas such as rocks, shallows, floating wrecks or other isolated dangers, as well as to indicate the entrance to ports*; statues and various frills are not required.

As already mentioned, many coastal church steeples were at the same time lighthouses; it cannot be excluded that this has led to giving the lighthouse not only the concrete function of saving human lives but also a function of saving souls and of "guiding in the darkness of the world" as some passages from the New Testament might suggest[18]. For example, considering *Christ the lighthouse who in the darkness of sin, with his light, guides the boat of the Church towards salvation* [7].

With the advent of radio beacons[19] which transmit electromagnetic waves (Morse signals) in every direction with a range of up to 200 miles, light beacons have lost some of their importance. Moreover, with current technology including radar, GPS and satellite phone is the classic lighthouse itself which is losing its importance even if in many cases it is still very active especially in a small sea like the Mediterranean.

[18] For example, see *John, 8,12; 9,5; 12,35; 12,46;* and *1st John 1,5* [38].

[19] *Radio beacon*: a fixed radio transmitting installation that allows a receiving station, installed on a ship or aircraft, to determine its position. *Non-Directional Beacon*s (NDB) are medium wave radio transmitters with an omnidirectional antenna that emit, with equal intensity in every direction, a signal with the name of the station. On board the signal is received by a radio direction finder (*Automatic Direction Finder*) which determines the direction of origin; the position of the beacon is shown on nautical and aeronautical charts. In 2002 the system was replaced by the GPS satellite system.

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THE QUARRIES IN THE COASTAL MUNICIPALITIES OF WESTERN LIGURIA: REFLECTIONS ON LANDSCAPE PROTECTION WITH A VIEW TO THEIR RECOVERY

Lorenza Comino, Simona Giovanna Lanza

Abstract: The coastal landscape, and in particular, to the extent of interest in the present work, that of western Liguria, constitutes one of the most delicate territorial areas that has undergone the greatest and most significant transformations. The coastal processes of industrialisation and urbanisation, linked above all to seaside tourism, have induced radical transformations, directly linked to the development of the railway, which in the 19th century drew a strongly built coastal landscape with bridges, tunnels, support works, and allowed the settlement and development of industrial and commercial settlements. Among these economic activities, mining activities, and in particular open-cast quarries, have contributed to the transformation of the landscape, due to their strong impact on the morphological structure of the territory. What we often read today as 'wounds' of the territory, have fed strategic sectors for the national economy, such as construction and infrastructure, with motives that are no longer economically relevant or sustainable from an environmental and landscape point of view, and need to be 'healed'.

In Liguria there are 383 disused quarries that, although small to medium-sized, represent a significant challenge. In western Liguria, out of 224 disused quarries, 78 are currently reused for tertiary or industrial or artisan purposes, 64 are spontaneously renaturalised, 11 are restored to their natural state and 71 are abandoned without plans. Most of them are located in the province of Savona, with about 46 % of the total number.

Through the analysis of a number of case studies, their formation, evolution and decommissioning, such as the Ghigliazza quarries in Finale Ligure, this work aims to draw attention to and stimulate reflection on the role that landscape protection can play in governing and directing the choices of reuse of particularly delicate situations from a landscape, environmental and economic point of view.

Key words: Protection, Enhancement, Coastal areas, Quarries

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Lorenza Comino, Simona Giovanna Lanza, *The quarries in the coastal municipalities of western Liguria: reflections on landscape protection with a view to their recovery*, pp. 573-588, DOI: 10.36253/979-12-215-0556-6.50

Introduction: the situation of disused quarries in Italy

The number of active quarries in Italy, as shown in the Quarry Reports prepared by Legambiente, has gone from 5725 in 2008 to 4168 in 2021, a 15 % decrease and a parallel increase in the number of abandoned ones from 13 414 in 2017 to 14 141 in 2021. In quantitative terms, these figures reflect the evolution of the mining economy. If, from the middle of the last century, they represented a strategic resource for the country's socio-economic development, linked to the important phase of industrialisation and urbanisation of those years, already from the second half of the 19th century, these phenomena underwent a slowdown that was also reflected in mining activities. The strong contraction in the demand for building materials led over time to the decommissioning or abandonment of industrial sites for the extraction of sand, gravel, limestone, ornamental stones, etc.

According to data available on the Liguria Region's geoportal, there are 383 disused quarries in Liguria. Although they are of medium-small size – 90 % have a surface area of less than one hectare - they represent a significant problem. Most are located in the Province of Savona (No. 176) with about 46 % of the total number of quarries, followed by the Province of Genoa (No. 90) with 23.50 %, the Province of La Spezia (No. 69) with about 18 %, and finally the Province of Imperia (No. 48) with 12 %. The Province of Savona thus emerges as the one with the most 'homogeneous' distribution of sites, both in numerical terms, since most of the municipalities in the province have an abandoned quarry, and in geographical terms, since quarries are distributed fairly evenly between coastal and inland municipalities. In western Liguria out of 224 disused quarries, 64 are spontaneously renaturalised, 11 are recovered in terms of landscape, 60 are currently reused for services or for industrial or craft purposes, 9 are reused for agricultural-forestry purposes, 9 are reused for residential purposes, and 71, 30 %, are abandoned without recovery projects (Fig. 1).

Figure 1 – Extract of the cartography of disused quarry sites in western Liguria (taken from the Liguria Region geoportal).

Quarry sites and regulations

National legislation on the extraction of solid minerals from mines and quarries still dates back to Royal Decree No 1443 of 1927, which distinguishes, on the basis of the material extracted, between first-category extractive industries (mines) and second-category industries (quarries and peat bogs).

The competences relating to the mining of non-energy minerals have been transferred, at different times, to the Regions (quarries by Presidential Decree No. 616 of 24 July 1977 and mines by Legislative Decree No. 112 of 31 March 1998 and Legislative Decree No. 83 of 22 June 2012), which have legislated on the matter.

As far as the Region of Liguria is concerned, the first regulation concerning the cultivation of quarries and peat bogs was Regional Law no. 12 of 10 April 1979, which defined the authorisation procedures to be applied to existing quarries, which at the time were not governed by sector regulations; this law introduced the Territorial Plan of Quarry Activities as a general framework for the exploitation of deposits in the regional territory. In 2012, the Region approved a reorganisation regulation: Regional Framework Law No. 12 of 5 April 2012, which was further updated and amended by Regional Law No. 18 of 2 August 2017. The objectives of this regulation are to reconcile the need to consider quarrying as an economic activity of primary importance with the protection of the environment and the landscape, as well as to achieve a simplification of administrative procedures.

Through the formation and approval of the Regional Territorial Plan of Quarry Activities (Ptrac), the regulation also aims to encourage the environmental restoration of the areas affected by quarrying. The Plan, which identifies the areas in which open-cast or underground quarrying and the storage of slate extraction waste may be permitted, is based on the principle, among others, of considering the transformation of the quarry territory as a temporary process oriented towards the best design solution for environmental recomposition and enhancing the mining areas for museum, tourist and recreational purposes, especially for sites with geological, naturalistic, historical and cultural value.

The Plan identifies as one of the criteria for the approval of a mining activity the contextuality between cultivation and environmental restoration and the identification of a boundary strip destined for works of reconnection to the context landscape that will have to guarantee an effective landscape harmonisation without interruption.

Open-cast quarrying activities shall not entail the overburdening of ridges that are significant for the coastline or for emerging views (Aurelia routes, historic conservation nuclei, Unesco sites), without prejudice to individual cases punctually identified by the project cards of the operating framework, where partial overburdening is compensated for by the reconstruction of a new ridge line that in any case occludes the view of the quarry from the coastline or from the significant views identified. In such cases, appropriate landscape and environmental compensation works will also be envisaged. As a general rule, the presence of natural cliffs and the memory of lithic elements is subject to enhancement.

In Articles 12-13-14 the plan currently in force (D.C.R. 26 May 2020 no. 7) indicates specific Landscape Disciplines for quarries and related structures that, as a function of the environmental and landscape recomposition of the site, envisage, at the conclusion of the quarrying activity, the demolition of all service buildings or in the planning stages that compensation and balancing of reductions in wooded areas and induced transformations be anticipated that indigenous plant species are used for renaturalisation works, composed according to patterns that can be traced back to the reference landscapes; that morphological discontinuity with the context is camouflaged.

The Plan, however, does not consider quarries that are no longer productive from the point of view of the exploitation of the deposit, limiting itself to a census of disused quarries with an excavation volume of more than 5000 cubic metres whose activity ceased prior to 2011 and disused quarries in the process of being abandoned.

Finally, the Region approved Regional Law No. 31 of 12 November 2014 containing the 'regulations for the recovery and valorisation of mining sites for museum, tourist and recreational purposes'. Although this is a purely procedural regulation, the aim of the legislation is to *regulate the procedures through which interventions can be authorised in order to:*

a) to promote knowledge and preserve the memory of the industry and work of the Ligurian community;

(b) encourage the environmental restoration of areas affected by cultivation, especially if they are degraded or in a state of neglect;

(c) encourage scientific research, training, education and dissemination;

d) expand the tourist offer and opportunities for conscious use of the regional territory;

(e) contribute to the sustainable development of economically fragile areas;

(f) ensuring safe public enjoyment of enhanced sites while preserving their essential characteristics.

In addition, the regulation states that the Region, among other things, shall approve the criteria and guidelines for the redevelopment of disused or abandoned mining sites. In fact, after a few years, the Liguria Region adopted the 'Guidelines for the design, management and environmental rehabilitation of open-cast and underground mining activities and related works' in 2019, updating them in 2021. With the aim of providing indications for a correct approach to the management of extractive activities, the guidelines, while envisaging the development of resource exploitation in terms of environmental sustainability, aim to minimise their impact, guarantee functionality, safety and productivity, rationalise the use of non-renewable natural resources, and, in any case, consider the recovery of the areas subject to excavation.

Providing some solutions for the recovery of the sites at the end of cultivation activity (such as the Remodelling of the slopes, also by means of backfilling, the Maintenance of the non-returnable front, with the execution of possible works for stability and landscape and naturalistic reintegration, the Reuse of the forecourt for activities consistent with the urban planning forecasts, after securing and arranging the front, the Creation of artificial basins for storing irrigation water or water to be used for different purposes), already in the introduction of the document it is anticipated that the new cultivation projects must be conceived and designed with a view to the final arrangement of the sites.

In the 'general binding criteria' for the design of cultivation and environmental restoration, the project performance requirements are indicated, among which, for what is of interest here, a primary role is played by the prediction of the final use, which *must be compatible and consistent with the landscape, environmental and urban surroundings*.

Moreover, among the principles that the project must follow, those dedicated to the recovery of the areas, as follows, find a prominent place, bearing witness to an increasingly incisive attention to the landscape and environmental aspects at the end of production: *"(...) 2. recovery must not be limited to the mere securing of the fronts, the accumulation of materials, the portals and slopes and the forecast of the dismantling of the facilities, but must also propose useful elements of territorial enhancement in coherence with the planning guidelines;*
3. environmental rehabilitation must be a complementary purpose during mining, so that the design must provide that rehabilitation works are carried out at the same time as mining and not relegated as a final act of exploitation;
4. the final destination of the site must envisage a configuration such as to fit adequately into the landscape context, in accordance with the provisions of the territorial and landscape planning instruments in force. As a general rule, and with particular regard to those cases where the quarry is included in the Natura 2000 Network areas or in areas suitable to constitute an ecological-functional link between sites, the final destination must prioritise naturalistic recovery in harmony with the vocation of the surrounding territory.

Pursuant to Article 1(4) of the aforementioned law, in the case of assets recognised as being of cultural interest, recovery and enhancement are carried out in compliance with the principle of cooperation between the State, the Regions and the local authorities as set out in Article 5 of Legislative Decree 42/2004 'Cultural Heritage and Landscape Code'.

In relation to mining activities located in areas subject to landscape protection pursuant to the above-mentioned Code and for the purposes of administrative simplification, especially with reference to potential discrepancies between what is authorised and what is realised and/or modified during operations, the guidelines, in Appendix 6, introduce the possibility of inserting "flexibility rules" with regard to certain well-defined situations such as the construction of service structures, plants, quarry fronts and relative internal tracks, access roads and, with regard to underground quarries, the size and positioning of access points.

As can be deduced from the above, the reference to territorial planning is very clear and pregnant. While Liguria can be said to have been particularly 'enlightened' back in 1990 with the approval of the Territorial Plan for Landscape Coordination (Ptcp), which is still valid today despite the attempts to overcome it with the new Regional Territorial Plan (Ptr), the same cannot be said in terms of landscape protection, considering the fact that the Landscape Plan envisaged by Legislative Decree 42/2004 has not yet been completed.

The current PTCP dedicates a special section to quarries and mines (Sec. IV), which are governed in particular by the plan's vegetation regulations concerning the landscape components consisting of the slopes, the hydrographic network, the flat areas on the valley floor, the coastline, quarries and mines, and landfills. Of particular interest for the themes of the present work is Article 88 in which there is already a brief mention of the issues of landscape-environmental recovery: the project must "establish the methods and phases of execution that ensure the progressive recovery of satisfactory environmental quality conditions".

The connection between quarrying activities and landscape protection is clear in the very definition of landscape, which the European Landscape Convention of 20/10/2000 defines as "a certain part of the territory, as perceived by populations, whose character derives from the action of natural and/or human factors and their interrelationships". Landscape thus understood as a static fact, all the more positive if it has remained intact in its original state, but a tension and mediation between nature and human activity that generates new balances or imbalances. In extractive landscapes, this dynamic vision is particularly evident if we consider the productive phase a transitional phase, representing important evidence of man's productive activity, towards new landscapes that may become of particular interest and to be enhanced.

According to Article 6 of the Cultural Heritage Code, valorisation, with reference to the landscape, 'also includes the redevelopment of buildings and areas subject to protection that are compromised or degraded, or the creation of new coherent and integrated landscape values'. Therefore, through the project of recovery, re-use, re-functionalisation, the objective to be achieved is that of a new landscape quality of the sites.

The protection and valorisation of disused and/or abandoned quarries, in the current state of planning in the Liguria region, is therefore entrusted to the aforementioned Code of Cultural Heritage and in particular to Part III, which, as is well known, concerns Landscape Heritage.

Indeed, as far as Part II - Cultural Heritage - is concerned, it is rather difficult to recognise the quarry site as a cultural asset of special interest; such recognition is more often limited to the elements of industrial archaeology that may be present within the sites themselves.

Therefore, the governance of these areas when they are located in areas subject to landscape protection (ex art. 136 or ex art. 142), whether it is a question of starting or continuing quarry cultivation activities, as well as to undertake environmental restoration activities, remains limited to the application of the Code as it is also necessary to obtain the landscape authorisation referred to in art. 146 of the same Code.

In this regard, it is necessary to recall the provisions of Article 131 on the protection and enhancement of the landscape, where it states that for the purpose of enhancement, to be carried out in compliance with the requirements of protection, the administrations shall promote the realisation of new coherent and integrated landscape values.

The recovery of abandoned quarries through examples

As can be deduced from the situation in western Liguria described above (90 quarries recovered compared to 224 abandoned) and from the examples that follow, the recovery of long-abandoned and disused extractive landscapes is a very complex issue, involving innumerable areas of specialisation, from landscape to engineering and economic.

Projects involving abandoned quarries, which are strongly conditioned by the morphology they have taken on during the cultivation phase, and by the profound environmental degradation in which they often find themselves, must also be confronted with the processes of naturalisation that have led to the creation of new ecosystems, sometimes even with singular characteristics.

The redevelopment of these sites has seen different types of redevelopment over time: spontaneous renaturation in 30 % of cases, reuse of the area for new functions, mainly industrial, for services and residential, and only two quarries in the whole of Liguria have been recovered for museum purposes (Gambatesa in Municipality of Ne e Masso in Municipality of Castiglione Chiavarese, both in eastern Liguria). While 30 % have no recovery plans or redevelopment processes have been underway for many years. It should be emphasised that the quarries located near the coast (about n. 90) have a recovery forecast mainly for residential purposes; this choice is obviously linked to the economic advantage due to the location, which makes the conversion operation economically advantageous for the owner of the area. The quarries are in fact mainly privately owned, and the intervention must be such as to guarantee an economic return, which as things stand, as far as western Liguria is concerned, seems to be particularly linked to residential solutions.

From this point of view, disused sites located in areas with a strong vocation for tourism and which, in the case of the examples given, have valuable archaeological, landscape and environmental features, are particularly interesting; these areas are highly attractive on the real estate market, capable of guaranteeing a business profit and compensating for the costs of securing the area, highlighting the need for a complex interaction between industrial activity and environmental conservation.

The subject of site safety measures is of primary importance, since they are necessary and indispensable whatever the reutilisation project may be, and are therefore a very conspicuous part of the intervention both from the point of view of the work required and from the economic point of view. Just think of the stability of quarry fronts that must be secured even in the event of their renaturalisation project in order to avoid dangers to public safety.

Ex Cave Ghigliazza a Finale Ligure (SV)

The Ghigliazza or Arene Candide quarry area is the largest disused quarry in Liguria, covering an area of approximately 400. It is located directly on the sea, in one of the most valuable landscape areas in Liguria, which includes the Caprazoppa promontory, one of the last undeveloped promontories on the Savona coast, the karst area below and the Arene Candide Cave, an important archaeological site, the only one in the western Mediterranean to bear witness to the almost continuous human habitation since the Upper Palaeolithic.

Figure 2 – Historical photo of the Ghigliazza quarry area.

The toponym Arena Candida has been attested since the 12th century and is due to the presence of a dune of siliceous sand, four hundred metres long and sixty metres high, that the winds had pushed against the Caprazoppa promontory. Due to its light colour and size, it stood out from afar and indicated the position of Finale to sailors. The dune characterised the area, so much so that, during the period of the Ligurian Democratic Republic (1798-99), the municipalities of the Finale area were united in the 'Jurisdizione delle Arene Candide' (Fig. 2).

The area is protected by landscape, archaeological and environmental protection through the declarations of interest of the Code of Cultural and Landscape Heritage (D.M. 24.04.1985, D.P.G.R. 29.03.1984, D.M. 08.06.1943, D.M. 05.05.1951, D. Lgs. 42/2004, art. 142, par. 1, lett. a) and g)), the special protection ZCS "Finalese - Capo Noli" (IT1323201), the Finalese Provincial Protected Area and the Borgio-Caprazoppa karst area (N. 29-SV) (Fig. 3).

Figure 3 – Aerial view of the Ghigliazza quarry.

The Territorial Plan for Landscape Coordination of the Finale area recognises among the distinctive features of the area the uniqueness due to geological and morphological features linked to the formation of the Finale stone and to the development of karst phenomena due to the erosive action of the Miocene sea; the landscape articulation of the Caprazoppa promontory; the remarkable value in terms of flora and phytogeography, with the presence of endemic species; a significant balance relationship between settlements and natural sites largely determined by the exclusive territorial specificities (morphology, geology, etc..). The Plan itself emphasises the interest in maintaining the achieved landscape-environmental balance unaltered, favouring in future developments a rigorous defence of the values described above.

Despite the exceptionality of the context, in 1800 Antonio Ghigliazza undertook an industrial activity with the firm Fratelli Ghigliazza, quarrying the sand that made up the 'arene candide' dune and the limestone from the cliff on which the dune rested, for the production of lime and glass.

The Arene Candide beach land was transferred by the State Administration with full rights to the brothers Angelo and Giacomo Ghigliazza with two successive contracts dated 22/10/1905 and 05/12/1912. In 1924, the dune removal activity ended, while the mining activity lasted until 1990, extending over the entire Caprazoppa mountain, for a front of about 500 metres and a depth of more than 400 metres (Fig. 4-5).

Figure 4 – Current view of the quarry area.

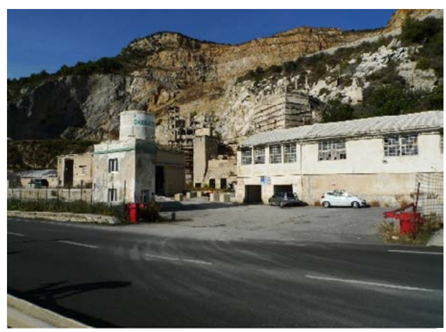

Figure 5 – The quarry front and the buildings serving the Ghigliazza quarry activity.

Starting in 2005, following the sale of the area, a long planning process began, which included the drafting of an Urban Operational Project aimed at securing and renaturalising the quarry fronts and, mainly, at building a new residential settlement with an annexed thalassotherapy centre, indoor sports centre, road network, car parks and public functions for a total of approximately 100 000 cubic metres of new buildings. The coexistence of archaeological, cultural and landscape interests also led to the involvement of the Ministry of Culture, which signed an agreement in 2008 to enhance the archaeological area.

Figure 6 – Photo inserts of the Ghigliazza quarry rehabilitation project for residential purposes.

Following an initial negative Environmental Impact Assessment opinion in 2009, the PUO was revised several times with the aim of reducing the overall impact on the landscape and the environment. Subsequently, four different projects were approved between 2009 and 2018, when the owner company filed for bankruptcy without completing the project (Fig. 6).

As things stand, the new owners, who bought the land at auction, are about to embark on a new planning phase that will have to deal with the changed sensitivity towards the landscape and the environment, as well as with the unresolved problems left by the last project regarding the securing of the fronts, the request for greater public use, the valorisation of the testimonial buildings in the entire area, and the volumetric reduction of the residences.

To date, 19 years after the first elaboration of the PUO, the project has still not been realised and the quarry and service buildings have been abandoned; furthermore, the project process will have to be restarted with new proposals.

Former Grimaldi Quarries in Ventimiglia (IM)

The Terre Bianche ex Grimaldi Quarries area covers an area of approximately 11000 square metres, in an area of scenic value that can be read in context as a green area within a considerably anthropised territory and that includes in the immediate vicinity Villa Hanbury with its internationally important botanical garden of the same name.

The landscape importance of the area is highlighted by the presence of extensive areas declared to be of public interest pursuant to Article 136 of the Cultural Heritage and Landscape Code (Ministerial Decree 24/04/1985, Ministerial Decree 14/01/1959, Ministerial Decree 28/02/1961) because the area "forms a natural framework of uncommon beauty", while the environmental character is highlighted by the special protection ZCS "Capo Mortola", due to the presence of Mediterranean coniferous forest habitats and rare and protected species of considerable biogeographical and endemic interest. On a geological level, the site is formed of arenaceous, calcareous, marly and argillitic lithotypes of considerable value and is included in the Grammondo karst area (No. IM-01) (Fig. 7).

Figure 7 – View of the Grimaldi quarry area.

The plan on the area, currently owned by the Grimaldi family, following a Programme Agreement, signed in February 2024 between the Municipality, the property, the Liguria Region and the University of Genoa, as concessionaire of the Hambury gardens, is to build a real estate complex for residential and tourist use for a total of 30000 cubic metres (Figg. 8 – 9).

In order to implement the intervention, it was necessary to proceed with a variation of the planning instruments. As far as the PTCP is concerned, the area was changed from a non-settled area, a regulatory area of *conservation*, to a non-settled area, a regulatory regime of *transformability,* thus modifying the primary objective of preserving the current situation without settlements, by virtue of the 'high naturalistic-environmental value', to an area in which it is possible to envisage settlement development.

The authorisation process, also from a landscape point of view, has not yet been completed and therefore the project has not yet been realised.

Figure 8 – Photo inset of the Grimaldi quarry reclamation project for residential use.

Figure 9 – Photo inset of the Grimaldi quarry reclamation project for residential use.

Figure 10 – Aerial view of the Italcementi quarry area.

Former Italcementi Quarries in Pietra Ligure (SV)

The area of intervention consists of the three disused Italcementi quarries in Pietra Ligure within a karstic area characterised by the Rocca delle Fene (No. 27-SV), the karstic hill of Trabocchetto and archaeological settlements dating back to the Early Iron Age (Fig. 10).

Figure 11 – The abandoned quarry site and service artifacts.

Mining activity began in the late 19th century at the oldest quarry, known today as 'Cava vecchia', and continued with the opening of several quarries for the extraction of limestone for the production of lime, especially from the 1930s until the 1960s. The particular type of quarrying, known as 'funnel' quarrying, can still be seen today in the quarries located close to the Via Aurelia and at the summit of Monte Trabocchetto, of which there are still remains of the tunnels created at the base of the funnel for the transport of the material descending by gravity.

The landscape importance of the area is highlighted by the presence of extensive areas declared to be of public interest pursuant to art. 136 under Ministerial Decree 20/03/1956 and art. 142 c.1 lett. a), c) and g) of the Cultural Heritage and Landscape Code. In terms of landscape planning, the PTCP identifies within the area the Emerging Artefact of the 'Archaeological Traces of Ligurian Settlement of the Early Iron Age' and identifies the site as falling within an area of scattered settlements with normative maintenance regulations (IS-MA). The project, a private initiative, got underway in 2006 with the planning of an Urban Implementation Tool for the "Landscape and Environmental Restructuring of the former quarries owned by Italcementi" (Fig. 11).

The subsequent Services Conference closed in 2011 with the approval of the intervention for the residential reuse of the former Italcementi Quarries, which envisages the construction of four housing lots, for a total of 140 flats or 42000 cubic metres (of which 16 % in Rocca delle Fene and 84 % in the Quarries area), a new urban park extending as far as the archaeological site of Pian dell'Olio, a panoramic lift connecting the historic centre to the hill, and new car parks (Fig. 12).

Figure 22 – Photo inset of the quarry rehabilitation project for residential use.

To date, 13 years after the project was approved, the project has still not been realised and the quarry and service buildings are abandoned.

Conclusions

The key aspects of the management and rehabilitation of abandoned quarry sites can be succinctly identified in their important historical and cultural significance, due to their long-standing activity contributing to the economic development and cultural heritage of the region and their consequent impact on the local economy, historically providing jobs.

It is clear, however, that these sites produce considerable 'impacts' on the landscape in which they are located: the removal of more or less large quantities of rock material creates significant alterations on the landscape, not only from an ecological and environmental point of view, with consequent effects on biodiversity and morphology, but also in terms of their visual impact.

The issue of quarry restoration represents a complex challenge in terms of landscape protection and recovery: transforming these sites into 'resources' for future generations by integrating their historical significance with landscape values in order to build a new sustainable landscape.

Whatever the rehabilitation project, abandoned quarry sites always present a 'degradation' situation due to the need to secure them (stability of quarry fronts, soil erosion, water contamination, etc.) on which it would always be necessary to intervene. Therefore, they constitute, even in the simplest case of their renaturalisation, an opportunity to create new landscapes as indicated by both the European Landscape Convention and the Cultural Heritage Code.

Going back to the notion of landscape as a relationship between man and the environment, typical of the identity of the places it represents, the projects concerning these particular areas cannot but place themselves in the wake of the sites' transformations while still preserving their identity. In this sense, the aim should be to achieve a new landscape quality that recognises and maintains the characteristics and peculiarities, including new ones that have come about following the abandonment of mining activity, of the sites.

With regard to the particular situation of the abandoned quarry areas in western Liguria, due in particular to their location on or near the coast and therefore characterised by the high real estate values that derive from them, little attention must be paid to the landscape values to be preserved, limiting the planning of interventions to the construction of more or less substantial building compounds.

Often, however, they are "out of scale", both in terms of the physical dimensions of the areas and the impacts that the new solutions produce, with respect to the territories of the municipalities in which they are located; this situation is reflected in an evident difficulty both in the planning itself and in the management of the authorisation procedures. It is no coincidence that all the examples reported have not been completed, having had approval processes lasting more than 10 years.

The protection of abandoned quarry sites, which is mostly limited to the need to obtain landscape authorisation, cannot prevent the above examples, as it can only reduce the volumetric impacts of new projects, be they residential or service projects, without being able to have a decisive influence on either reuse choices or design quality.

In Liguria, more than in other regions, there is a lack of studies that build up a wealth of knowledge of quarry activities that could lead to targeted and conscious planning of the future of these areas, a prerequisite for the construction of territorial policies. Building up a wealth of knowledge would allow implementation at various planning levels and would form the basis for large-scale valorisation. The drafting of the Regional Landscape Plan could be an opportunity in this sense, but unfortunately its drafting has been at a standstill for some years. The PPR would be the right place to outline the future transformations of degraded areas, as provided for by Article 143 of the Cultural Heritage and Landscape Code, identifying the significantly compromised or degraded areas and the enhancement measures compatible with the protection requirements, to be submitted to specific agreements between the actors involved, such as Programme Agreements and Institutional Agreements.

Experiences in other Italian regions that have quarries similar to Liguria in terms of location in areas of particular landscape and environmental value and extension, such as Tuscany and Sardinia, show that the instruments to be entrusted with the valorisation of these sites are mainly theme parks, geo-mineral or archaeological parks connected with each other and with the identification of specific routes, capable of integrating the mining and geological values with the landscape values present in the territory.

Other experiences indicate how nature redevelopment and the creation of educational and hiking trails can create new landscapes, such as the Parco della Cave in Milan, the quarry in Bareggio (MI), the quarries in Botticino (BS) or the Le Chiesuole nature area within the Parchi del Ducato in Emilia.

Therefore, to give just one example, it can be considered that, among the cases cited, the Arene Candide quarry, given its landscape, historical and archaeological characteristics, could be the subject of cultural, educational and social projects that would enhance the Finale area, going beyond the purely economic vision of land exploitation for speculative purposes.

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ARCHAEOLOGICAL MARKERS BELOW THE LAGOON WATERS

Elisa Costa, Carlotta Lucarini

Abstract: This paper focuses on the documentation of some archaeological case studies in the northern part of the Venice lagoon, an extreme and at the same time vulnerable ecosystem. The study emphasises the challenges of working underwater in this environment and the necessity of incorporating both traditional and modern digital techniques. Through the use of different technologies, such as Multibeam Echo Sounder, topographic surveys with the total station and DGPS, and photogrammetry, it is possible to reach a high level of detail in the documentation and analysis of the archaeological contexts. The data management with GIS software allows an efficient and easier consultation and the effective dissemination of the research results. Thanks to the synergic use of these tools, it is possible to produce an entire overview of underwater archaeological sites, which implies enormous advantages for their understanding and analysis of archaeological markers. The methodology we tested in this highly complex environment turned out to be crucial also in monitoring the state of conservation and degradation of underwater archaeological heritage.

Keywords: Underwater archaeology, Digital techniques, Lagoonal landscape, Photogrammetry, GIS

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Introduction

Coastal stretches are rich in archaeological evidence that testifies to the long-lasting interactions of ancient communities with the aquatic environment. Nowadays, all these contexts are greatly influenced by ongoing climate and environmental changes, such as the rising sea level and several linked geological phenomena that affect both the landscape and the archaeological remains with increasing intensity. In order to study and understand these modifications, archaeological evidence in micro-tidal areas can provide significant information. Especially ancient coastal structures, such as maritime villas, piers, fish tanks, embankments and building foundations, can be crucial [2]. In particular, the analysis of submerged and semi-submerged archaeological contexts in lagoon waters, a very peculiar and enclosed environment, can testify to the impact of anthropic modifications on the landscape, but it can also enable the establishment of significant markers of ongoing sea level changes.

In this paper, we will analyse some case studies located in the northern part of the lagoon of Venice, Italy. This ecosystem poses a significant threat and requires protection and monitoring from both an ecological and environmental perspective, as well as an archaeological one. Our work focusses on the use of modern technologies applied in such peculiar environment. Working beneath the lagoon's waters is indeed particularly challenging due to multiple factors. The integration of traditional and digital techniques, along with the synergic use of the different survey methodologies, enables the acquisition of precise metric documentation and accurately dimensioned digital models, turning out to be indispensable for documenting underwater archaeological sites.

The use of GIS in the management of the different data resulting from these investigations and surveys allows, on the one hand, an immediate and easy visualization of the research results, and on the other hand, to carry out detailed analyses of the spatial data and assess the changes to which the contexts are subjected.

Materials and Methods

From 2020 Professor Carlo Beltrame from Ca' Foscari University coordinates different project in the northern part of the Venice lagoon[1]. An important part of the projects is carried out in collaboration with geomorphologist Paolo Mozzi of the University of Padova, to deeply analyse and reconstruct the paleo-environment of the lagoon and the relative sea level changes.

This area of the northern lagoon is highly affected by the tidal variation due to the proximity of the inlet. This implicates: strong currents, depending on the direction and the moment of the day, which affect the work operations; relevant tidal excursion, which has to be carefully identified for the acquisition of

[1] Interreg Italy-Croatia UnderwaterMuse Project; Prin 2022 - The lagoon of Venice in Antiquity. Settlement dynamics, adaptive behaviours, paleoenvironmental reconstructions; PNRR CHANGES SPOKE 1 - Historical Landscapes, Traditions and Cultural Identities.

measurement data; high erosion, which affects the state of preservation of the archaeological sites; and poor visibility (from a maximum of 2-3 metres near the sea, in optimal conditions, to a few tens of centimetres in the innermost parts) mostly due to the dense and thick sediment, which is constantly being moved by the currents. The general working conditions in this environment can be sometimes very difficult. Hence, based on the environmental and archaeological context, each dive must be meticulously planned, to identify the best methodology and the most suitable techniques for documenting the sites even in difficult circumstances [10].

The case studies consist of three contexts dated to Roman times, that are nowadays completely submerged in the lagoon waters. In particular, the analysis has been conducted in two channels: San Felice channel, which is part of the tidal delta created on the Lido-Treporti inlet, and Rigà channel, a branch of the first one (Figure 1).

Figure 1 – Localization of the archaeological sites in the northern lagoon of Venice (reconstruction of ancient shoreline elaborated from [18]).

The first site in San Felice channel consists of a Roman well-cistern built in bricks. This structure, discovered in 1984 by Franco Tonello and the subject of an investigation campaign promoted by the Archaeological Superintendence of Veneto in 1987 [13], is composed entirely of *sesquipedali* bricks[2]. It forms a rectangular base of approximately 7 x 8 m, which lies directly on the seabed without foundation piles. Following investigations conducted in 2020, it was

[2] It is a “provincial” type of brick which measures approximately 44 cm x 29,5 cm x 7,5 cm in thickness [19].

possible to reinterpret the site, initially identified as the base of a tower. Thanks to the many similarities found with some other Roman structures, it was possible to attribute to this artefact the function of a well-cistern, dating back to the 1st century AD or to a slightly later period [6].

The second one, located in Ca' Ballarin, in San Felice channel, is part of a bigger complex, in which another cistern has been found. The Roman pier and cistern, dated to the second half of the 1st century AD - 3rd century AD, have been discovered in 1997, and two excavation and restoration campaigns have been carried out in 2002 and 2003 [12, 13]. The site is composed of a well-cistern built in *sesquipedali* bricks and a fragmented longitudinal structure made of cement conglomerate and stone chips. Seven large blocks are collapsed towards the centre of the channel, while one is still in its original position, supported by structural poles, near the current shore. These remains can be ascribed to a quay or a pier and, together with the cistern, are presumably part of the ancient waterway network used for navigation, of which the San Felice well-cistern was perhaps also part.

The last case study is an *ostrearium*, again made of *sesquipedali* bricks associated with wooden structures at Lio Piccolo [7, 9, 16], in Rigà channel, at a bathymetry variable between -1 m and -4 m below main sea level. The site is currently being investigated and will be the subject of upcoming excavation campaigns. The structure is composed of a basin for the conservation of oysters connected to several wooden structural poles, which retain evidence of some foundation bricks.

The documentation of the sites was conducted through instrumental (multibeam), digital (photogrammetry), and topographic (total station, trilateration, and DGPS) investigations; the combined use of different technologies has been fundamental in order to obtain a composite and multifaceted archaeological documenttation.

Non-invasive acoustic investigation methods play a significant role in the mapping of submerged cultural heritage, also in lagoon areas at shallow depths [3, 21]. These systems allow visualising the submerged environment, mapping the bottom, and identifying and monitoring the archaeological heritage with high levels of detail through a dense point cloud. The depth and width of the S. Felice channel allowed an instrumental survey carried out in collaboration with the Elmar Marine Survey Company of Venice. Using a Multibeam Reson Seabat 8125, the seabed of an area of approximately 45000 m^2 was investigated in order to identify the portions of structures already documented in the 1980s.

The topographic survey of the targets positioned on the site is essential as a reference for an accurate scale, metric control, and local and global orientation of the photogrammetric model of the site. Furthermore, it is fundamental for the purposes of the overall survey of a submerged structure documented in portions (as San Felice well-cistern and Ca' Ballarin pier) and for the documentation of a stratigraphically excavated site (as Lio Piccolo *ostrearium*). In the underwater environment, we usually carry out the topographic survey through the Direct Survey Method (DSM), a trilateration technique with linear measurements, applied for the first time in 1982 and optimised in the late 1990s [5, 8, 17, 20]. It consists of the direct and inclined measurement of the targets through the use of a rib and a depth gauge. The positioning of the targets must follow a certain pattern so that the measurements allow obtaining the xyz coordinates of the points.

The shallow depth of the lagoon waters and the presence of a nearby shore allow the use of the total station and differential GPS for the topographic survey, improving the precision of the target coordinates [1, 5]. Following the experience obtained in the previous underwater activities [4], in the case studies examined, where the maximum depth is -4 m, we have applied the two different techniques. The first step was to use a total station with a pole long enough to keep the prism out of the water. To maintain the verticality of the rod, we applied a weight to the base and a polystyrene float to the top, where a spherical level was inserted for greater precision. Then, a differential GPS on a floating buoy with a tied rope on the underwater targets was used; for every target, we have realised between 20 and 30 measures to calculate the barycentre of the point cloud, delete the major errors, and obtain the most accurate point (Figure 2).

Figure 2 – The two instruments employed for the topographic survey: a. the long pole with prism of the total station; b. the buoy with DGPS.

The photogrammetric survey was realised following the limitations imposed by the tides[3]. It has been executed during the two favourable moments: the last phase of the rising tide, when the suspension is minimal because the water no longer carries the sediments of the lagoon bottom with it, and the inversion of the tide, when the strength of the current decreases until it reaches the moment of no current (called "dead water"), before changing direction. Despite this precaution, it was not always possible to document the sites on a daily basis because visibility was not sufficient or the speed of the current, and therefore the suspension, were excessive.

[3] For the methodology followed in data acquisition and processing, please refer to the procedures already described in [14], [11], and references.

The final stage of our study was the integration and correlation of all the data into a GIS environment, a tool that is quite common and indispensable in archaeology nowadays. We built our QGIS project by creating specific modules able to describe the archaeological sites in as much detail as possible, with the possibility of attaching images and other types of files. In addition, we created spaces that could house and manage all the elements derived from our studies: archival site plans, topographic and bathymetric data, photogrammetric models, orthophotos and photomosaics, point clouds, Digital Elevation Models (DEM), and vector and raster layers.

Results

Through the methodology and the techniques described, we can therefore claim to have established an effective procedure for detecting, documenting, georeferencing, analysing, monitoring and making visible the submerged heritage in lagoon waters.

From the MBES data acquisition we obtained a georeferenced DEM of the well-cistern in San Felice Channel and an accurate bathymetric map of the seabed. Through the survey of the surrounding area, we were able to discard the hypothesis of the presence of other related archaeological structures or anthropic elements, which had initially been presumed. From the obtained bathymetric profiles of the channel, we could also identify the structures that are in a more eroded condition, making them more susceptible to preservation threats.

The application of digital photogrammetry, despite the difficulties in a lagoon context, allowed us not only to obtain metrically correct digital 3D models and to create point clouds and DEMs with millimetric accuracy (Figure 3), but also to produce an entire overview of the underwater archaeological sites, which implies enormous advantages for its understanding and appreciation, in particular in this specific case, where a site is never completely visible.

The measurements taken using the total station and DGPS allowed us to obtain the correct positioning and orientation of the sites, which is essential for photogrammetric processing but also for correct georeferencing of the evidence.

The storage of all data in a GIS environment allows for easy management of documentation, interpolation of different types of data, and, above all, visualisation and interrogation (Figure 4). Along with the creation of digital models, it is also an effective tool for disseminating research results.

In the case of the Lio Piccolo site, where excavation activities have been going on for four years, the management of all documentation (planimetric and phase plans, location of the different structures and artefacts) is easy and immediate, which makes an underwater site where visibility never goes beyond one and a half meters, comparable to any stratigraphic excavation in a dry environment.

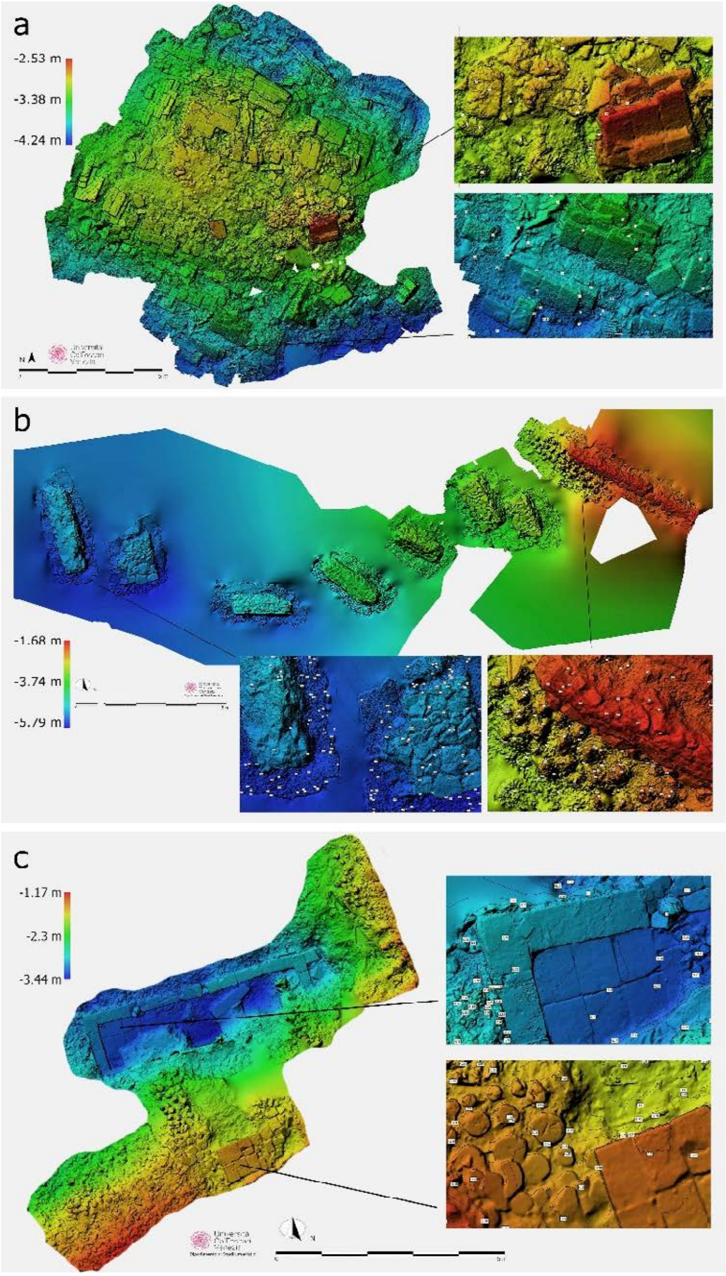

Figure 3 – DEM of the three case studies with detailed bathymetric measures. a. San Felice well-cistern. b. Ca' Ballarin pier. c. Lio Piccolo *ostrearium* (elaboration: authors).

Figure 4 – Digitised planimetric map of Lio Piccolo *ostearium* in GIS environment after the 2023 campaign. Base map: orthophoto from drone. In the tabs: detailed photos of the different elements (elaboration: authors).

Discussion

From the studies we are conducting in the northern lagoon of Venice, it arises that the use of digital photogrammetry turned out to be crucial for the documentation of the submerged archaeological contexts [10]. The combined use of this technique, together with MBES surveys of the areas, and the elaboration of DEM make it possible to achieve a centimetric level of detail in measurement and bathymetric data. The correct system of topographic survey consents to georeferencing exactly the evidence; the storage and management of all the different types of data through a GIS platform permit the analysis and monitoring of the situation in a very precise way; furthermore, it makes possible an easier and more immediate consultation and visualisation of the data and the effective dissemination of the research results. The combination of these factors allows for a comprehensive and precise understanding of the archaeological context, which would otherwise be impossible.

The documentation of the underwater cultural heritage, in fact, play a key role in studies on subsidence rates and variation in the RSL, turning these contexts into highly reliable archaeological markers. The base of the *ostrearium* at Lio Piccolo lies today at a depth of -2.95/-3.20 m below the main sea level, whereas the foundation bricks above wooden poles lie at a depth of 1.35 m below the main sea level. According to the studies carried out on Relative Sea Level (RSL) in Roman times for the Venetian lagoon, which is estimated to be around -1.4 ± 0.7 m [7, 15, 22], it emerges that the basin must have been in a submerged environment when it was built, whereas the foundations structures were just above the water level. This is perfectly in line with the function of the complex. In the same way, the portion of the pier in Ca’ Ballarin, which is still in situ lying on the structural poles, can be considered an important marker for the analysis of the relative sea level in Roman times. This dock/pier structure, which now lies at -1.8 m, needs to be installed on the channel bank, and out of the water, in Roman times.

Moreover, with these digital technologies and methodologies, we can effectively monitor the underwater sites and heritage. In two cases, we have been able to identify the damage that the structures have suffered in recent years. After analysing the plans that were drowned during the excavation of the cistern and pier [12], we have detected that one of the blocks on the pier at Ca’ Ballarin is now in a different position. Block A probably slipped along the side of the channel due to strong erosion; it lies capsize at a deeper bathymetry, and the foundation piles are now exposed (Figure 5). In the case of the San Felice well-cistern, photogrammetric surveys carried out over a two-month period revealed that a corner of the elevation wall, which was in the original position, collapsed towards the outside of the structure, probably due to anthropic causes, such as anchor mooring of boats, that have capsized the block of bricks (Figure 6).

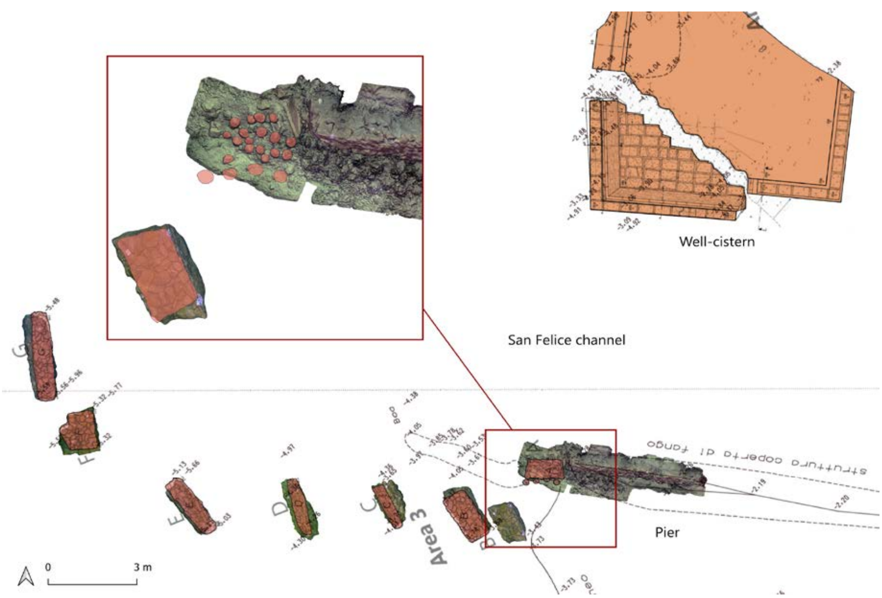

Figure 5 – Orthophoto from photogrammetric survey and digitization in GIS of the Ca’ Ballarin well-cistern and pier. In the rectangular sections, the capsizing of block A of the pier is evident (elaboration: authors).

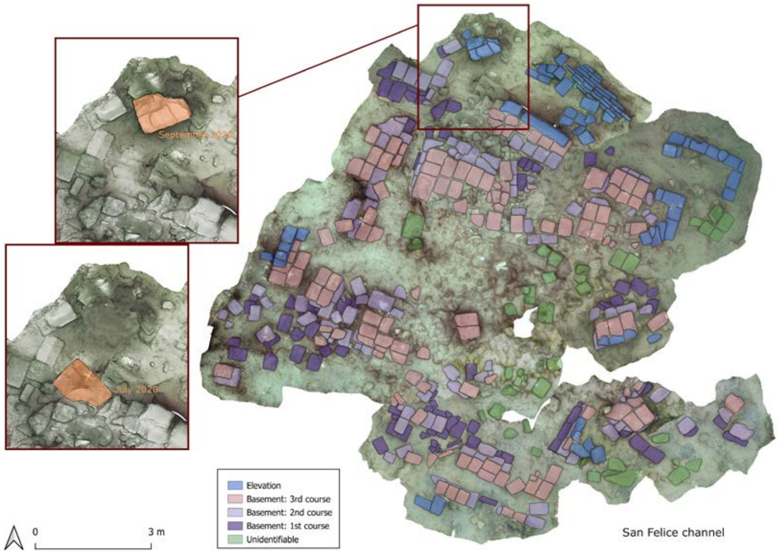

Figure 6 – Orthophoto from photogrammetric survey and digitization in GIS of the basement and wall of the San Felice well-cistern. In the rectangular sections, the movement of the corner of the wall from July to September is evident (elaboration: authors).

Conclusion

The search for a non-invasive data acquisition methodology that would facilitate accurate documentation of material evidence has always been a primary objective of archaeology. This study demonstrates that the most modern digital technologies respond perfectly to this request, allowing useful documentation for both study and conservation. Due to its unique and extreme characteristics, the lagoon environment requires careful selection of the strategy to implement. The integration of Multibeam Echo Sounder, topographic surveys with total stations and Differential GPS, and digital photogrammetry has proven crucial in documenting and analysing submerged archaeological contexts in lagoon environments with high accuracy. The methodology employed allows for the meticulous georeferencing, monitoring, and visualisation of underwater archaeological sites with a rigour and neatness never reached in the history of underwater archaeology in the lagoon of Venice. The use of GIS software has further enhanced data management, enabling efficient consultation, detailed analysis, and effective dissemination. The combination of these technologies has led to a comprehensive understanding of the submerged heritage, facilitating the monitoring of conservation and degradation states. Moreover, the digital technologies used have provided valuable insights into relative sea level changes, turning these archaeological contexts into reliable markers for studying environmental changes.

Acknowledgements

The team of underwater investigations of Ca' Foscari University was coordinated by C. Beltrame. The logistical and technical support was supplied by the Idra company of Venice. This research is partially supported by the PNRR Project - CHANGES SPOKE 1 "Historical Landscapes, Traditions and Cultural Identities" CUP H53C22000850006.

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DOI: 10.1016/j.earscirev.2016.02.002.

WHEN GEOLOGY BECOMES CULTURAL WEALTH: PRAIA A MARE, TOWN OF CAVES

Giampiero D'Ecclesiis, Antonella Pellettieri

Abstract: The geological conformation of an anthropized place decides the fate of the women and men who live in that portion of territory. Praia a mare, called the city of the island due to the presence of the imposing island of Dino, is actually characterized by the presence of many caves both on the mainland and on the island. The life of men has taken place in these caves since the Paleolithic age: in its largest cave there are the geological signs of the sea that reached it but also the drawings of the Paleolithic men who settled this cave. And in this same cave, designated the largest in Europe, there is the Sanctuary of the Madonna della Grotta, patron saint of Praia a Mare. And Greek monks settled in the nearby caves since the early Middle Ages, founding monasteries and places of spirituality. But Greek monasticism has also left signs of its passage on the island, as is also clear from the name of one of the caves, called the Monk's cave. And again in a cave on the island, the body of Vitigno was found, the hero of Praia who defended the city from an assault by the Turks led by Amurat Rayt who, in 1639, attacked the island of Dino with six vessels. It is probable that the first settlement of Praia took place between the 15th and 16th centuries by Schiavoni, probably coming from Ragusa, today in Croatia, who occupied the caves on the mainland, forming the first residential nucleus of the town and giving the name of Plaja Scavorum.
In this contribution, a precise census was carried out of the caves present in the Praia area so that they could become part of a redevelopment project through the cleaning of some earth caves covered by vegetation that had grown over time and by debris and by the protection of the sea caves so that all can become a tourist route with the creation, first of all, of signs to be fixed in front of each cave to know its name, geological characteristics and any historical episodes that have occurred there.

Keywords: History, Tourism and Landscape of the coastal areas, Enhancement, safeguarding and dynamics of the territory

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)
Giampiero D'Ecclesiis, Antonella Pellettieri, *When geology becomes cultural wealth: Praia a Mare, town of caves*, pp. 601-613, DOI: 10.36253/979-12-215-0556-6.52

Text

The stretch of Tyrrhenian coast between the mouth of the Noce River and Torre San Nicola is located along the Tyrrhenian margin of the southern Apennines and represents the north-eastern edge of the structural depression of the Gulf of Policastro subject, during the Quaternary, to extensional tectonics linked to the opening of the Tyrrhenian basin which caused extensive uplifts of this portion of the coast of which the widespread marine terraces represent a witness.

This stretch of coast includes a small strip of Lucanian territory and extends into the territories of Tortora and Praia a Mare.

The area in question is delimited to the north-west by the Noce river valley and is characterized by the presence of reliefs that show a certain degree of morphological maturity; there are numerous marine terraces that interrupt the profile of the coastal slopes starting from rather high altitudes (180 m above sea level).

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Recent studies, on the basis of existing and detected marine morphologies[1], have analyzed in detail the evolution of this coastal sector characterized by a generalized uplift lasting for the entire Pleistocene period, with limited episodes of subsidence in localized areas, and also active during the Holocene.

A first marine entry into the sector under examination is witnessed starting from the beginning of the Lower Pleistocene. with the entry of the sea into the paleovalley of the Noce River on an area previously occupied by glacis and by the fluvial conglomerates of the Tortora paleofiumarella.

The summit shelf of the Island of Dino appears correlated with that of the Foresta district and shows, overall, a transversal profile characterized by stretches of surface with different inclinations (Fig.1) which, also including the shelf of the Island of Dino, surpasses the 2 km. This leads us to believe that the entire terrace was shaped during various changes in sea level and that it is, like the high terraces in the area of the mouth of the Noce river. a polycyclic terrace.

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In the area of the mouth of the Noce river, at the time of the formation of the marine terraces currently at an altitude of 140 m, a gulf must have existed.

The subsequent stabilization of the sea level at around 90 m, referable to the Middle Pleistocene, appears well represented in the area near the mouth of the Noce river and can be correlated with the surface present on the top of Dino Island: this testifies to the continuation of the phase of uplift even after the Early Pleistocene.

Therefore, the coastal trend between the Lower Pleistocene (Santernian) and the Upper Pleistocene - as a function of the overall uplift of the area, albeit characterized by local subsidence episodes of some limited sectors - would have seen a progressive substantial advancement towards the west of the coastline in the S. Domenica area of Talao/S. Nicola Arcella up to the current position and a phase of marine intrusion, which probably occurred in two phases during the Lower Pleistocene, in the paleo-Noce valley until the establishment of a real gulf located between Praia and the Serra di Castrocucco and, subsequently filled by the alluvial deposits of the Noce during the subsequent uplift phase of the area.

It is clear that the geomorphological evolution of the territory is strictly conditioned by the widespread presence of carbonate rocks affected by karst phenomena that developed over time in close correlation

with variations in the base level.

There are numerous karst cavities known and registered in this area which are currently in direct contact with the sea or which have been in direct contact with the sea in the past: such cavities abound along the perimeter of the Island of Dino and along the coast of Praia a Mare.

Some caves are in direct contact with the sea such as, for example, the Blue Grotto and the Lion's Grotto; others are found at a level slightly higher than the current sea level such as, for example, the Grotta del Frontone which has numerous lithodome holes on the walls as evidence of the period in which it was invaded by the sea.

Other caves are found below the current sea level such as, for example, the Gargiulo Cave which is located 15 meters deep and extends for over 124 meters and, probably, is connected upwards to the Grotta del Frontone. Even the large Grotta della Madonna, located close to the town of Praia, shows on its walls the signs of marine organisms (litodomes), witnesses of the era in which this cave was connected to the sea.

The island of Dino located in front of Contrada Fiuzzi in Praia a Mare is the largest island in Calabria. It is about 500 m from the coast and can be said to be almost joined to the mainland by a chain of rocks very close to each other which are the last remnants of that stretch of land which once united it and to which it will once again become connected, in the not too distant future.

Whichever way you look at it, it looks like a small but massive plateau emerging from the sea, with mostly very steep sheer walls. Where the coasts are overhanging, they are completely bare, sometimes for their entire height, up to a level of about 10 m higher than the line of the leaf; where the slope is not excessive, however, you can often see thick bushes clinging to the rock.

The summit terrace of the island of Dino, as already mentioned, which can be connected to the coast with the same morphology present in Contrada Foresta, hosts conglomerates and sands of the coastal terrace, generally brown and reddish and whose clasts are predominantly calcareous-dolomitic.

Among the numerous caves on the Island of Dino, interesting for their position or characteristics, are that of "dei Colombi", "di Punta Frontone", "del Monaco", "delle Sarde", "del Tondo", "Azzurra", “Grazia”, “Del Leone”, “Gargiulo”. The Colombi cave is more of a hollow dug by the sea than a real cave and has traces of lithodome holes which allow us to measure a previous sea level. The Punta Frontone cave is accessed from a rocky platform located approximately 3.00 meters above sea level. and extends for about 12 meters in a north-east direction.

Of interest is the presence of earthy sediments inside the cavity which has, right up to the innermost parts, lithodome holes on the walls, evidence of the intrusion of the sea into it. It is interesting to note how, at a depth of about 15 meters on the vertical of the Punta Frontone tunnel, the vestibule of the Gargiulo cave opens up. Both caves, both the Frontone and the Gargiulo, testify to a phase relating to a different basic level: the first with the marked shoreline at an altitude of 12 m above sea level starting from the lithodome holes found on the rocky coast of Praia and the second with the terraced morphological surfaces detectable around the Dino island, between 9/12 meters deep[2].

The Grotta Grazia opens at about 15 meters above sea level and extends for about thirty meters in a southerly direction: the presence of numerous small stalactites and small stalagmites in the final stretch up to 30 centimeters long, suggest the presence of dripping for at least a thousand years.

The numerous caves present in the coastal sector of Praia a Mare represent an interesting testimony to the post-Miocene evolution of this sector of the Southern Apennines: it was affected by an evolution connected to neotectonics and to the variations in the base level connected to the glacial phases and interglacials and which followed one another from the Lower Pleistocene to the Upper Pleistocene.

It is interesting to note how some of these, such as Mulino (20 m above sea level), Saraceni (20 m above sea level), Vallone Papalio (300 m above sea level), della Mina (17 m above sea level), still constitute delivery points for underground water circulation.

The Grotta della Madonna (40 m above sea level), although about 500 meters from the sea, has traces of lithodome holes on its internal walls, unmistakable signs that it has been lapped and affected by the sea.

The morphological elements present in the area - from the terraces along the lower valley of the Noce river to the flat depositional and erosional surfaces present numerous along the coast of Praia and in correspondence with the Island of Dino and together with the karst morphologies - allow us to reconstruct with good clarity the geomorphological events that have sculpted the territory and the environmental variations that have occurred.

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[2] Ferrini G., Mendicino P., Toccaceli R.M. (1994) - *Caratteristiche morfostrutturali ed evoluzione recente dei fondali dell’Isola di Dino (Calabria nordoccidentale, Italia)*. Mem. Descr. Carta geol. D’It. LII (1994) pp.135-148.

Table 1 crosses the recognizable morphological elements mentioned in figure 1 with the paleoenvironmental conditions and the eras, allowing us to obtain an interesting picture of the Pleistocene-Holocene evolution of the territory.

Such a precise geological description makes it very clear to us why, on the back of a postcard sent in 1937, we read these words: "On the Napoli Battip line. Reggio visit the wonders of the Praia Caves, the magnificent caves rich in superb stalactites, the "Blue Grotto" of the Island of DINO where there are also the ruins of a temple of Venus. Come, admire again the stupendous Grotto of the Madonna with the gigantic openings, and with the symmetry, and the surprising light where nature has prepared enchantments and surprises... Station: "Praia d'Aieta-Tortora". Therefore, ever since then it was very clear that tourism could become a significant source of economic progress even if the tourism that they were trying to convince, with those words, was not a distracted mass tourism but one made up of cultured travelers who felt an interest in visit both the sea caves and the land caves. And the earth caves were described with gigantic openings which are the main characteristic of these very large cavities. And therefore, ever since then, it was very clear that geology was the most important asset of Praia a Mare and one to focus on for the future. It should also be specified immediately that, in 1937, Praia a Mare had been an independent municipality for 9 years: with Royal Decree no. 813 of 29 March 1928, Vittorio Emanuele III brought together the municipalities of Aieta and Tortora into a single municipality called Praia a Sea, with capital in Praia. The three municipalities became autonomous again in 1937.

Praia a Mare, even if its official history began only in 1928, in reality, was an inhabited area that existed since the Upper Paleolithic as shown by some graffiti - but evidence of the Metal Age is also evident - found inside the immense cave of the Madonna within which the primitive Praia settlement began to form[3]. Praia a Mare was a district of Aieta and was a city without a name for a long time: for the inhabitants of Aieta who, as we read from the sources, lived in Praia from November to June due to the clemency and mildness of the climate[4], the name was beach of Aieta. The same beach had been called Plaga Scalorum, Schiavoni beach, in reference to the arrival of Schiavone populations around the mid-15th century after the fall of Constantinople to the Turks and the great migrations of Albanians, Greeks and Schiavoni to the Italian coasts[5]. The peculiarity is that a beach that has the name of beach (Praia derives from the Latin term plaga) only became Praia a Mare in 1937, an unfortunate clarification because it is difficult to find beaches in the mountains or in the plains. At most a beach can be near a lake or a river! But

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[3] Guida G. (1991) - *Aieta. Pagine della sua storia civile e religiosa*, Cosenza, p.11.

[4] *Monografia sul Santuario di nostra Donna della Grotta nella Praja degli Schiavi e sul Comune di Ajeta in Provincia di Cosenza per VINCENZO LOMONACO giudice della Gran Corte Civile di Napoli e socio dell'Accademia Ercolanense, Cosentina, Pontaniana ed altre,* Terza Edizione, Tipografia della Sirenza, Strada Nuova de' Pellegrini n.20, Napoli 1858, p.10.

[5] Pellettieri A. (2022) - *...in finibus Lucaniae. Historical cartography of the Tyrrhenian coast and demographic fluctuations*, in Bonora L., Carboni D., De Vincenzi M. Matteucci G. (eds) *Monitoring of Mediteranean coastal areas: problems and measurement techniques* Ninth International Symposium (Livorno, 14-16 June 2022) Firenze University Press, pp.855-864.

that there was not much generosity in giving the name to settled places is also clear from the toponym Foresta, today the district of Praia, a location located on the upper part of Praia and which implies there was a forest not to be confused with a beach!

Description of a particular beauty and historical interest on the landscape and its caves is found in the first texts published on local history[6] but I report the words of a printed supplement found on a Facebook page dedicated to Praia (and which is unknown the year of printing): " …*Una spiaggia vastissima, quasi sterminata, si stende fra l'abitato ed il mare. Di fronte s'erge dall'acqua, come colossale balena, l'isola di Dino. Essa segna il termine del golfo di Policastro, ed apre variamente i suoi fianchi per mostrare diverse magnifiche caverne, nelle quali penetra il mare; e, tra queste, non sai quale ammirare di più. Superba ne è una, detta* azzurra*, dai riflessi cerulei dell'acqua; migliore, ma meno fortunata di quella di Capri. Magnificamente nel vero senso della parola é l'altra appellata del* Frontone*, dentro cui si resta estatici dinanzi alle bizzarrie della natura, che ha formato delle strane Catacombe con laberinti, colonne pensili, archi, cupole, piani cristallini ecc. Oscure grotte s'interrano nelle rupi a tergo dell'abitato; ma sono un incanto per le stalattiti e le stalagmiti, che s'incontrano, s'incrociano e formano ancora qui colonne, archi, cupole, fughe di porticati, meraviglie di prospettive, incantati edifici sotterranei, illuminati fantasticamente dalla scarsa luce esterna o dalle torce a vento portate dai visitatori*"[7]

But it is emblematic that one of the first documents handed down to us about Praia so far contains the following words: "ecclesiam sancti Zacharie, que est iuxta mare suptus Aitam, et totam vineam, que est circa eam, una cum cripta, que est juxta eam and the whole land, which comes from Falconara to the Mali canale"[8]. A recent study has identified the church of Santa Zaccaria on the small hill in front of the Fiuzzi tower: determining in the fairly precise description is the indication of the place located on the sea "sotto Aieta" near a vineyard and a cave, beyond the identification of the Falconara district and the Male Canale. This is a cave located under this small ridge right on the beach, on the seashore, on the ridge, today, there is a well-known nightclub surrounded by olive groves. This cave was hidden by vegetation for a long period and it was possible to identify it with the help of period photographs.

The toponymy linked to the caves is also decisive: the Monaco cave identified on the island of Dino confirms that the church of San Nicola was located on the island, as demonstrated in the same study cited previously.

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[6] Poliorama Pittoresco, t. II n.5, p.3g., 1837; *Aieta in Dizionario Geografico-storico-civile del Regno delle due Sicilie del Sig. Raffaele Mastriani*, Napoli 1838, t.2, pp.117-120.
[7] Facebook page *Praia com'era*
[8] Mattei-Cerasoli L. (1938) - *La badia di Cava e i monasteri greci della Calabria superore*, in "*Archivio Storico per la Calabria e la Lucania*", VIII, pp. 177-178.

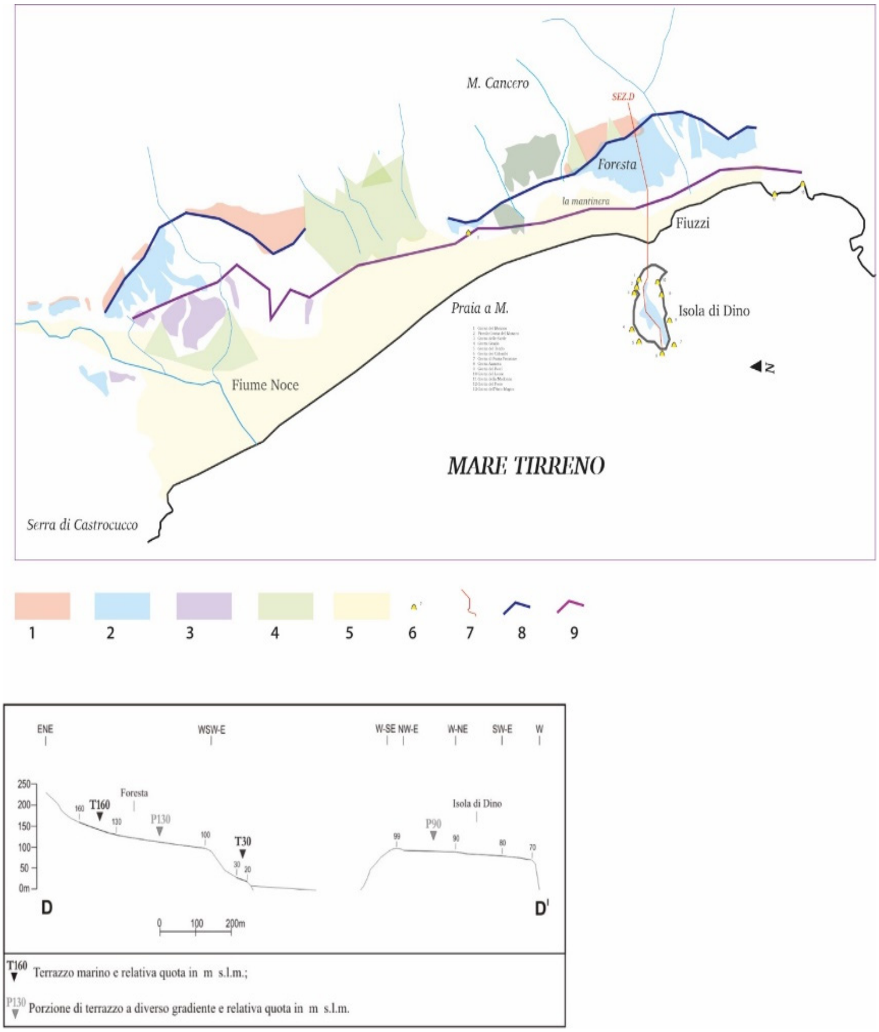

Figure 1 – Geomorphological scheme of the area: 1) Debris strata; 2) Erosion and depositional terraces on limestone substrate (140 - 139 m above sea level). Early Pleistocene; 3) Erosion and depositional terraces on limestone and conglomerate substrate (75 – 70 m above sea level). Middle Pleistocene. 4) Fluzio-torrential fans (Holocene). 5) Recent alluvial and coastal deposits (Holocene). 6) Main karst cavities; 7) Trace morphological profile. 8) Upper limit of terrace 140-139 m. Lower Pleistocene 9) Upper limit of terrace 75 – 70 m. Middle Pleistocene.

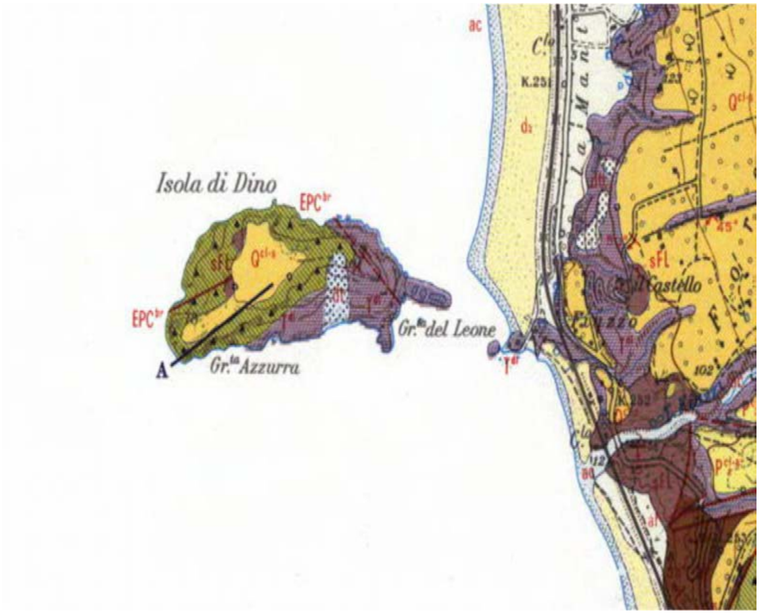

Figure 2 – Geological scheme of the Island of Dino: Qcl-s (conglomerates and sands of the coastal terrace, generally brown and reddish whose clasts are predominantly calcareous-dolomitic – Pleistocene); EPCbr (calcareous breccias passing laterally to calcareous conglomerates and calcarenites, containing fragments of Upper Cretaceous limestones and some rare elements of a siliceous nature - Eocene – Paleocene); Tdl (fine-grained dolomites and recrystallised limestones, generally dark grey, locally well stratified - Trias).

Table 1 – Recognizable morphological elements and paleoenvironments of the Praia a Mare area.

	Sector between the Castrocucco peak and the mouth of the Noce river	**Sector Praia – Dino's Island**
low pleistocene	PaleoNoce outline, coastline at the edge of Castrocucco peak	Submerged Dino s Island, Emerged coast at north of Serra della Rosa, Serra della Rosa promontorio a mare
low pleistocene inferiore	Emiliano-Siciliano, transgression of the sea in the paleoNoce valley, Coastline-120-140 m s.l.m	Dino s Island subsidence, Terrace at the top in Foresta area and on the top of Dino s island at 90 m on sea level
medium pleistocene	coastline at 70 and at 40 m s.l.m.	coastline 75, 30, 20 meter
high pleistocene	coastline at 3 - 5 metri	coastline 3 - 5 meter
Olocene	shoreline groove +2 – 0	shoreline groove +2 – 0

	Depth	età B.P.
submerged terraces of the Dino's Island	25 meters	28-36 000
	12-9 meters	6-7000
	3-4 meters	5-6000

Table 2 – Summary of the Quaternary chronology with indication of the chronological windows accredited for the main recognized hominid types.

QUATERNARY PERIOD								Homo		
PERIOD	EPOCH	Age/Stage		Age/Stage		GLACIATIONS Name / Phase				
Quaternary	Holocene	Meghalayan		0	4200					
		Northgrippian		4200	8200					
		Greenlandian		8200	11700					
	Pleistocene	Tarantian		11700	129000	Wurm	glacial			
		Ionian		129000	774000	Riss-Wurm	interglacial			
			NeoTyrrhenian			Riss	glaciale			
			Eutyrrhenian			Mindel-Riss	interglacial			
			Crotonian			Mindel	glacial			
		Calabrian	Sicilian	774000	1800000	Gunz-Mindel	interglacial			
		Gelasian	Emilian	1800000	2580000	Gunz	glacial			
			Santernian			Donau-Gunz interglacial	interglacial			
Neogene	Pliocene	Piacenzian								

Erectus
Neanderthal
Sapiens

The document reports: "*que Mercurii nuncupatur abbatiam Sancti Petri que dicitur Marcanito, et ecclesiam Sancti Helye et Sancti Zacharie cum omnibus relevanceis earum, et ecclesiam Sancti Nicholai de Digna cum vineis et terris et silvis et marino portu, et abbatiam Sancti Nicholai de abbate Clemente cum vineis et terri et silvis et ecclesiam Sancte Venere cum casale*"[9].

This description speaks of three churches located in the territory of Praia and, in addition to the aforementioned church of Santa Zaccaria, the presence of a church of San Nicola de Digna is specified; with Digna we mean the island of Dino and on it there were vineyards, lands and a port. The port was well described in 1837 by Vincenzo Lomonaco: "...vi è un'isoletta di circa due miglia di circuito, appellata isola di Dino, con un porto capace di potervi comodamente stare circa venti bastimenti da carico. Ella è molto amena, e nelle scogliere, che sonovi nel suo giro, vi si trovano degli eccellenti frutti di mare, come patelle, dattili…"[10]. The port reported since 1065, date of the document reported above, is important to narrate another episode of the history of Praia in which another cave is the protagonist. We must report, again, the words of another volume by Vincenzo Monaco from 1858: "... ... *In questo luogo [isola di Dino denominata Dina nel XIX*

[9] Pratesi A. (1958) - *Carte latine di abbadie calabresi dell'archivio Albobran*dini, Città del Vaticano, p.254.

[10] *Aieta* in *Dizionario Geografico-storico-civile op. cit.*, p.118.

secolo], ebbe morte onorata un tal Vitigno condottiero degli Ajetani che in agosto 1639 combattè valorosamente contro t Turchi che capitaneggiati d'Amurat Rayt con sei vascelli prima assalsero Dina; di poi Scalea, onde furono respinti dal Principe Francesco Spinelli che vi lasciò miseramente la vita come narra Giannone Stor. lib. 35. cap. 1. Ciò avvenne essendo Viceré di Napoli il Conte di Lemos. La morte di Vitigno é decantata con mediocri versi dall' Abate, Molitemo (Poesie Liriche Nap. 1760 p. 166). La tradizione di questo avvenimento si conserva tuttora dai terrazzani, e si ripetono di frequente i versi che descrivono il coraggio e la pietà di quell' eroe e martire cristiano, il quale ferito letalmente, sopraffatto dall'oste che discendeva folla dai legni barbareschi, ebbe rifugio io un antro, ove si trovò poi spento intriso nel sangue col rosario in mano, ineffabile conforto dei veri credenti nell'ora solenne del supremo tragitto"[11].

It is not possible to identify in which cave Vitigno died but it was certainly one of those located near the Monaco cave (if not the Monaco cave itself).

Yet another event in the history of Praia has a cave as its setting and in some earth caves it is possible to identify the church of Sant'Elia. The literature on the subject identifies this church in the cave named below. Grotto of the Madonna. Around this cavity there are many others at different levels of height on the face of the mountain onto which they open.

Other documents from the 1160s describe the situation of the Byzantine theme of Calabria which was divided into two turms: one of these is mentioned since the 10th century in a hagiographic text "*con il suo centro ad Aieta; essa sicuramente a Nord si estendeva sino al Noce che costituiva la frontiera del tema di Calabria; e ad Ovest sino alla turma del Merkurion, che apparteneva al tema lucano*"[12].

It should also be noted that there is still toponymic memory of a district of Sant'Elia which is located near a very large cave, the sanctuary of the Madonna of the Praia a Mare cave, which has a series of small caves around it which could be the cells in which the monks of the church of Sant'Elia were hospitalized.

We agree with the hypothesis that the church of Sant'Elia was located near the cave of the Sanctuary of the Madonna[13] if not inside the Marian sanctuary also in consideration of another document which shows that the church and/or the monastery of Sant'Elia was the same one to whom about a century and a half later, precisely in 1198, Giovanni Scullando, lord of Aieta, donated some funds near Petricella, including the 15 farmers employed in their cultivation[14].

The most important cave for the inhabitants of Praia a Mare and the best known is, therefore, that of the Madonna within which stands the church dedicated to Maria Assunta, protector of Praia. Once again the words of Lomonaco help us to

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[11] *Monografia sul Santuario di nostra Donna della Grotta,* op. cit. p.10 e 19.20.

[12] Guillou A. (1974) - *Geografia amministrativa del Katepanato bizantino d'Italia*, in *Calabria Bizantina. Vita religiosa e strutture amministrative*, Atti del primo e secondo incontro di Studi Bizantini, Reggio Calabria, pp. 120-121.

[13] Moliterni B. (2003) - *La chiesa di San Zaccaria e l-origine del Santuario della Madonna della grotta di Praia a mare*, in *Archivio storico per la Calabria e la Lucania* LXIX (2003), pp.19-26; *Idem* Moliterni B. (2013) - *Alfano*, *Pietro e la diocesi di Policastro*, LXXIX (2013), pp. 7-36.

[14] Trinchera F. (1865) - *Syllabus graecarum membranarum*, Napoli, n. 243, pp. 328-329.

tell the mythological beginning of this event: *"Il Capitano di un bastimento Raguseo il 1326 sospinto da una procella, e dall'avversione de' marinai parte Saraceni e parte Iconoclasti alle sacre immagini, abbandonava sur un sasso della prefata grotta una immagine di nostra Donna. Dopo due anni, o in quel torno, risolcando gli stessi mari, compiacevasi fortemente che gli abitanti di quelle vicine montagne marine, avendole innalzato una cappella, l'osservavano come speziale protettrice"*[15].

The fabulous story helps us identify at least two aspects: popular legend reports that the sea reached the cave but this happened long before 1326 as geology informs us. The huge cave - formerly home to the church/monastery of Sant'Elia - was transformed into the church of the Madonna and, subsequently, into a sanctuary. Let's not forget that the cave preserves traces of human activity in the Paleolithic. We cannot omit Lomonaco's precise description of the sanctuary, a place of profound devotion of the Praia people but also of all the neighboring towns: "*Quivi dalla parte di occidente vedesi una famosa grotta addimandata la grotta del cardinale Spinelli discosta 250 metri dal mare. Dal basso dell'arena dopo un'erta collina, e dopo aver ascesi molti gradini, si giunge alla prima grotta che forma un atrio con altissima cupola. Quindi dopo aver montati più di 50 gradini perviensi all'ingresso della grotta grande, la cui figura è triangolare, ma alquanto ineguale. Alle due estremità avvi delle aperture naturali donde piove nell'antro copiosa luce, è di un'altezza mirabile, e dal mezzo del lamione cade una stilla perenne di acqua limpidissima che riempie un pozzo in mezzo alla stessa: il suo circuito è più di piedi 800. Camminando a man dritta dopo alquanti scalini si ascende ad un altare dedicato alla Vergine dell'Assunta, e pochi passi lontano se ne scorge un altro. Serpeggiando le massicce pareti della grotta veggondi delle sabbie ammonticchiate, ove giace molto ossame, che ti ricorda i tempi tristissimi dell'oligarchia feudale, e dell'asprissima ostinatezza dei guerrillas calabres*i"[16].

The geological conformation and the thousand-year events in the history of Praia a Mare are closely connected to the sea and land caves and we are not wrong in giving a double surname to this town: Praia a Mare, city of the island and of the caves.

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[15] *Aieta* in *Dizionario Geografico-storico-civile del Regno delle due Sicilie* op. cit., p.120.
[16] *Ibidem.*

Figure 3 – Isola di Dino, Grotta del Frontone.

Figure 4 – Isola di Dino, Grotta Azzurra.

Figure 5 – Cave of the Sanctuary of the Madonna and neighboring wall with large caves.

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THE LATIUM COAST FROM OSTIA TO CIRCEO: SETTLEMENT DYNAMICS IN A PECULIAR CONTEXT

Alessandro Maria Jaia, Laura Ebanista

Abstract: The contribution aims to investigate the settlement dynamics of the Latium coastal stretch of approximately 100 kilometres between Ostia and Circeo. This is a strip characterized by peculiar geomorphological and hydrographic features which have determined the outcomes of settlement dynamics starting from prehistoric times. After the protohistoric settlement process, also defined by the presence of watercourses and basins, the Latin cities developed in the coastal and para-coastal strip and found their economic basis on the control of the landings. Coastal basins and their landing places and watercourses are fundamental elements in the definition of economic processes and territorial control. The fundamental *caesura* of the settlement process for this area is 338 BC. The Roman conquest determined a series of dynamics that will be highlighted in the contribution proposed in the light of the relationships of the urban centres with Rome and with each other. Finally, an example on the settlement dynamics of the southernmost district is presented. It is the area historically known as *Palus Pontina* characterized by a greater thinning out of settlements and by peculiar dynamics.

Keywords: Latium coast; Ancient Topography; Settlement dynamics; Lacustrine areas

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Alessandro Maria Jaia, Laura Ebanista, *The Latium coast from Ostia to Circeo: settlement dynamics in a peculiar context*, pp. 614-625, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.53

Introduction

The stretch of Latium coast between Ostia and the Circeo promontory is 100 km long (fig. 1) and is characterized by peculiar geomorphological and hydrographic features: low and sandy dune coast and a system of lagoons which in ancient times occupied about half of the entire coast strip [6 and 2, pp. 13-41]. The flat conformation of the coast, which is interrupted only by the modest relief of Capo d'Anzio and by the Circeo promontory on its southern edge, has been decisive in the context of settlement dynamics over the long term.

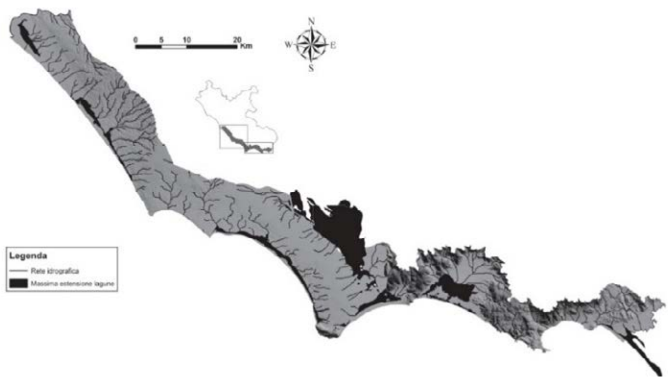

Figure 1 – Southern coastal Latium with maximum extension of the lagoons [2, p. 40].

In the northernmost part of this coastal stretch is the Tiber delta [3, p. 783] where the outermost portion was formed with the solid contributions transported by the river, while the innermost area is a flat territory with altitudes close to sea level which correspond to the area of the ancient lagoons. Immediately further south-east, the coastal strip (fig. 2), characterized by dune sands, is internally contained by pyroclastic flows due to the contribution of the so-called Latium Volcano. The hinterland of Aprilia and Anzio presents a hilly system made up mostly of ancient dune sands which caused, at least until the last reclamation of the last century, strong seasonal swamping phenomena. The so-called «piscine», large depressions, were formed among the dunes that collect the water that does not flow into the sea due to the low slope of the territory [21, p. 23]. More southern, the clastic material due to the activity of the Volcano combined with the contribution of sediments from the watercourses filled the marine basin on the slopes of the Lepini Mountains, determining the formation of the Ancient Red Dune, fundamental element in the formation of the peculiar geological and hydrogeological conformation of the Pontine Plain, characterized by wide marshes, regulated several times over the centuries. The substratum of the plain contains an aquifer fed by the mountain system flowing through the Mesozoic limestone rocks, determining some resurgences (e.g. Ninfa Lake, for example). The minimum slope of the territory, the sometimes-lowest level of the internal soils compared to the external ones, the subsidence of a few centimetres every year, the coastal dune which often blocks the mouths of rivers and ditches and the lack of continuity in drainage through the centuries has always slowed down the water flow towards the sea generating extensive swamps. In the coastal stretch these marshal areas took the form of narrow and elongated lagoons, parallel to the coast. The lake basins between the Tiber and Anzio have been completely reclaimed and to date there is no trace of their presence in the modern landscape. South of Astura River, however, after the systematic reclamations undertaken in the Pontine Plain several times up to the 1930s[1], only some of the southernmost basins remain today, reduced in size and contained by concrete embankments: Fogliano, Monaci, Caprolace and Paola or Sorresca lakes[2], for a linear extension of approximately 20 km. The Circeo promontory represents a clear element of *caesura* within this system with its limestone composition (Lower Lias) [4].

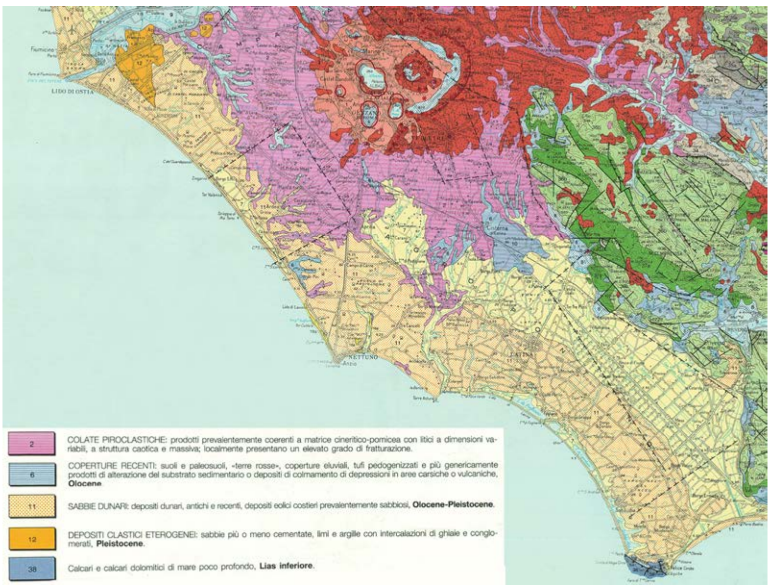

Figure 2 – Lithographic-structural model edited by Regione Lazio, excerpt [4].

The research presented here constitutes the synthesis and the integration of multiple data acquired in the context of territorial research carried out by the

[1] After the reclamations of the Roman age known from ancient sources and after a discontinuous abandonment of the area in the Middle Ages, we remember, among the most important and incisive for the organization of the territory, the reclamation undertaken under the pontificate of Sixtus V in the 16th century and the famous reclamation of Pope Pius VI in the 17th century.

[2] Paola or Sorresca Lake is the only one not regulated with concrete embankments during the works of the 1930s, but it retains its natural appearance full of inlets.

authors in which survey data on the territory also converge. The aim of the research is the diachronic investigation of the settlement dynamics of this stretch of coast, considering the fundamental relationship between man and the environment in a territory with peculiar characteristics and in which the dominant element is the water: lagoons, rivers, ditches, and historic channellings.

Prehistory and protohistory

Already during the prehistoric age, the population develops along the internal dune system, which overlooked the coastal lagoon, and along the natural waterways. These were slightly raised areas suitable for exploitation for fishing and harvesting. The coast of lower Latium is characterized by the presence of a series of waterways, natural or artificial, which connect the coast with the hinterland, crossing the dune and the lake system.

In the southernmost district examined here as an example, although the Pontinian phenomenon integrally concerns the entire coastal strip, along the western bank of the Astura river, near Quarto delle Cinfonare, a deposit attributable to the Lower Paleolithic was identified, further south, on the eastern shore, in the toponym Valle dell'Oro, materials relating to the Upper Palaeolithic. Along the course of the Moscarello ditch in Borgo Maria (Podere La Rosa), were instead materials dating back to the Middle and Upper Paleolithic have been found [19].

Furthermore, the discovery of very abundant lithic industry referable to the Pontinian (Middle Paleolithic) along the entire coastal strip behind the external aeolian dune is decisive in understanding the dynamics of the population. This is material that is largely found in the area corresponding to the ancient lagoon and moved from the internal dune system (whose difference in altitude is now imperceptible) due to the numerous anthropic excavations, fills and natural run-off [9, pp. 35-36, 63, 69, 72, nn. 34S, 87Sa-h e 125S] (fig. 3).

Figure 3 – Hypothesis of the ancient lagoons and river system for the coastline south of Astura with prehistoric finds. 1: Quarto delle Cinfonare; 2: Valle d’Oro; 3: Podere La Rosa; 4: Colle Parito; Unnumbered points: lithic Pontinian industry highlighted during the surveys [9].

For the protohistoric age the situation is not extremely dissimilar with the attestation of anthropic frequentation along the waterways and with new attestations along the internal side of the coastal dunes. This phenomenon is documented, starting from the north, in the territory of *Lavinium*, a proto-urban centre with the first attestations referable to the Middle Bronze Age. Here, along the line of the external dunes, concentrations of two types of objects have been identified in several places (fig. 4). The first type includes rough chalice vases, recently identified also in the Caprolace lake area [1] and perhaps attributable to the sea salt extraction process [15]. The second type consists of a series of tuff objects, dating back to the Final Bronze Age 3, worked in the shape of *glandae missiles*, dated within a very broad chronological span, always found in areas connected to lakes, lagoons, and swamps. Examples are known in Latium (along the dunes of Pomezia, Ardea - Torre San Lorenzo, Minturno), in other regions of Italy (Comacchio 3rd century BC, Frattesina Polesine in the context of the Final Bronze Age) and in part of the Mediterranean (e.g. in Greece, to Magoula Balomenou, site of Sarakinos Cave, near Orchomenòs – Boeotia in the context of the Neolithic; Tunisia, Carthage; Turkey, Ulucak, hinterland of Smyrna) [17, pp. 24-25]. It is difficult to identify the function of these objects attested in tuff, stone and pottery but they seem to be either weights for nets of 'rezzaglio' type or projectiles for hunting in the swamps [15]. Some unpublished specimens found in Rome in a votive context of the Middle Republican Age in the area of the Circus Maximus have been interpreted as votive slingstones, but the relevant data that emerges is the proximity of the place of discovery to the Tiber River rather than the function, still doubtful[3].

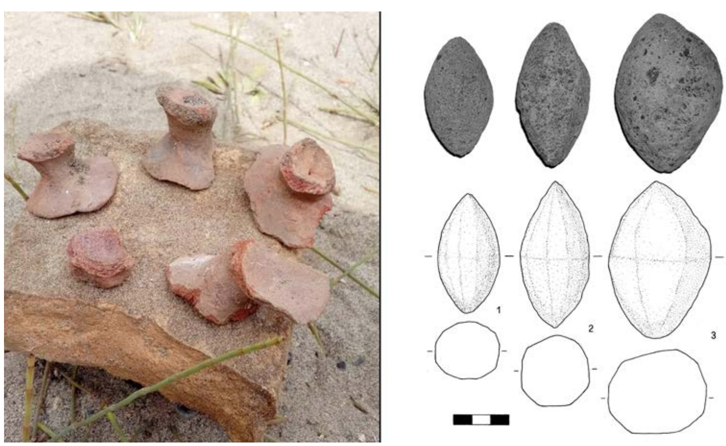

Figure 4 – On the left rough chalice vases attributable to the sea salt extraction process; on the right tufa object, worked in the shape of *glandae missiles.*

[3] Exhibition: The Rome of the Republic. The story of archaeology – Rome 2024 - Capitoline Museums.

Evidence referable to the Bronze Age and the Iron Age are attested near the lagoon overlooking the *plateau* occupied by the proto-urban centre of *Ardea*, findings referable to the Middle Bronze Age 2A in the Tor San Lorenzo area and to the Final Bronze Age at Tor Caldara [2, pp. 58-59; 65-71]. The area that will then be occupied by the urban centre of *Antium* has yielded numerous evidence of attendance starting from the late Bronze Age, as demonstrated by sporadic materials and the excavation of necropolis areas.

The oldest presence on the acropolis of what will later be the city of *Satricum* dates back to the Middle and Recent Bronze Age; starting from the end of the 9th century BC instead, a village of huts is documented [16]. Attendance along the Astura and Moscarello waterways continued in the protohistoric age with dynamics like those of the prehistoric age.

Historical age

After the protohistoric settlement process, also defined by the presence of watercourses and basins, the Latin cities developed in the coastal and para-coastal strip and found their economic basis in the control of landing places. Coastal basins and their landing places and watercourses are fundamental elements in the definition of economic processes and territorial control. The urban centres developed in their internal relationship between the inhabited area and the port (fig. 4).

Figure 4 – Landings and harbor on the coast between Ostia and *Circeii* before the Roman conquest (base: IGM 1:25.000 series 25/v, mosaic).

Considering on the northern limit the mouth of the Tiber, with respect to whose relationship with the city of Rome it is not necessary to dwell, we encounter proceeding in a south-eastern direction: *Lavinium* and the *Sol Indiges* sanctuary at the mouth of the *Numicus* river (Campo Ascolano), Ardea and the *Castrum Inui* sanctuary at the mouth of the Incastro ditch, Colle Rotondo and the Sant'Anastasio ditch, *Antium* and Capo d'Anzio, *Satricum* and the landing at the mouth of the Astura river, *Circeii* and its harbour on the western side of the promontory. In the absence of urban contexts along the cost south of Astura and before the Circeo promontory, the *Clostris* - Rio Martino binomial seems to be a fundamental topographical junction.

Considering that the coast by its natural conformation is without natural ports, in all cases the coastal settlement which act as landing places develops at the mouth of a watercourse: river, ditch or built canal. The use of internal lagoons, as part of a cabotage activity, as a resting place should also be considered in this context.

The difference between the coast north and south of *Antium* is evident, determined by the distinct hinterland with the southern presence of the Pontine plain between the sea and the Lepini mountains. In the archaic and late archaic periods, these two different landscapes corresponded to two different socio-political contexts: to the north the community of the Latins and to the south that of the Volscians, who advanced from the south until settling along the *Antium* - *Satricum* - *Velitrae* axis. In this context, we note the piracy activities that characterize the economy of the Volscians of Anzio which reach as far as the eastern Mediterranean. Even if this "traditional" activity practiced on such a vast scale, seem to be a strong point for the Volscian populations, it is, in reality, an indication of residual economic activities, practiced by communities that control territories that they are unable to make productive reaching in this way the *surplus* of valuable goods they need. Meanwhile the coastal Latin communities of *Ardea* and *Lavinium* and inland (Colli Albani), involved in the continuous wars against the Volscians and in tensions with Rome, also suffered a notable economic stagnation. Not unrelated to this economic regression of the late archaic period is the reduced production panorama of the individual Latin city-states, which also lacked a large and unified market.

The great caesura from a settlement point of view was 338 BC, the year of the Roman conquest of Latium.

Along the entire coastal arc from the Tiber to Circeo there is notable economic growth due to the Roman reorganization: new city *elites* in the historic Latin cities; strong increase in the Viritan distribution of the land; foundation of new *coloniae romanae* (*Antium* and probably Ostia) and the revitalization of the Latin colony of *Circeii*; furthermore, the unification of the markets and the free movement of goods. This period lasted until the late 2nd century BC when the conquest of the Mediterranean, Greece and Carthage brought substantial changes in the economic and political perspective of Rome. The descendants of the *coloni* who widely occupied the countryside of the Latium coast and the early hinterland moved en masse towards more promising territories and markets.

Also in the period following Romanisation, the fate of the Latium coast seems to be divided into two areas with two different outcomes: the one north and south of *Antium*. The construction of Via Appia (312 BC) certainly falls within the scope of this great mutation (fig. 5). To the north of *Antium* the coast is widely occupied with productive settlements at the mouths of the waterways (on average there is a settlement every 2.5 km). This phenomenon develops to the detriment of the area behind it; the Appia, in fact, passes near the Alban Hills and therefore the area that receives the greatest benefits is precisely the one at the foot of the hills. Meanwhile, the via Appia has a great influence in the Pontine Plain where, after *Cisterna Neronis*, constitutes a straight line that reaches Terracina, cutting across the plain, without crossing any of the urban centres located upstream (*Cora*, *Norba*, *Setia*, *Privernum*), nor downstream (*Satricum*).

Figure 5 – Location of the main centers after the Roman conquest and the construction of the Via Appia (base: GoogleEarth)

The main road artery certainly determined, in the long term, the movement of road traffic to a more internal area, resulting in a loss of importance of the coastal area. If already in the mid-4th century BC, as material data attests, the city of *Satricum* had ceased to exist as an urban centre and its relevance was linked only to cult of the *Mater Matuta*, the episode of the fall of lightning in 207 BC, mentioned by sources[4], determined the end of use also of the sanctuary. This certainly is contributed to a progressive abandonment of the natural landing place at the mouth of the Astura river. The archaeological data testify a dense population in the immediate hinterland between the Astura river and the Circeo in the

[4] Liv. *Ab Urbe* 28, 11, 1-3.

Republican age, attested by villas and farms set on the strip, modestly at altitude (30-45 m above sea level), located about 6 km from the modern line of coast. In this southernmost area, whose settlements are further apart due to the natural distance between the waterways, there is evidence, starting at least from the 2nd century BC, of aristocratic residences related to the suburban *otium*.

The production of amphorae seems to attest to how the coastal stretch of lower Latium falls within the Campania economic system rather than the Roman one.

The northernmost place where the production of amphorae is attested is Astura, where a manufacturing workshop producing Greco-Italic amphorae and Dressel 1 is attested in the place where the villa will later be built [18].

Pontine Plain

Below is an example of the Pontine district, a peculiar territory as it is characterized by an extreme distance of urban realities from each other, as well as, as is known, by a particular situation connected to water management.

At a moment that cannot be better defined in the Late Republican period, there was a thinning out of the presence of settlements in this internal area, as demonstrated by the material data relating to surface surveys undertaken in the last 50 years [20; 9, pp. 32, 37-40]. At the same time, however, it is only the places located on the coast, at the confluence of rivers or ditches, that preserve continuity for settlements, even until the late imperial age. Among these, proceeding from the north, the villa of Astura, built on the *insula*, located immediately north of the mouth of the river, the villa located at the mouth of Moscarello ditch, totally destroyed by the rectification undertaken during the regimentation of the 30s of the last century [9, pp. 37-39, 61, n. 8S] and further south, between Fogliano and Monaci lakes, the settlement located at the mouth of the Rio Martino, with phases of occupation from the 1st century BC until at least the 4th century AD, as attested by the funerary inscription of Kamenio, owner of the villa in the late imperial age and there buried [9, pp. 50-56, n. 11F and 12]. The role of these waterways is decisive at this point because they constitute lines of penetration perpendicular to the coast which allow the hinterland to be reached, first up to the via Appia and then, through the foothill route, up to the Lepini centres. This system of waterways is joined by the coastal cabotage system in the lagoons, effectively defining the route systems for this section of the Pontine plain, according to two travel lines: along the coast and from the coast to the hinterland. For the routes along the coast, just think about how the coastal route of the so-called Via Severiana, known, although without a name from the Tabula Peutingeriana. For the stretch between *Astura* and *Circeii* the route integrate road routes and waterways along the coastal lagoons and the canals that connect them (and partially connected them even in ancient times), which essentially follow the path of the Fossa Augusta, a canal with a dual function of disposing of marsh water and navigation from the mouth of the Tiber to Avernus Lake, commissioned by Nero, but left unfinished at his death [13].

It is not a case that all these waterways (natural and artificial) constituted, during all the historical regimentation[5], part of the hydrographic system for the canalization of water and its flow into the sea, maintaining a topographic value, often also defining boundaries.

The topographic place located at the mouth of the Rio Martino deserves a dedicated mention (fig. 5). It is an area for which there are no attestation of the existence of inhabited centres, in fact, proceeding south of Astura, the first attested urban centre is *Circeii*. From an archaeological point of view, on the southern bank of the canal, probably excavated for the first time as part of the reclamation of Cornelio Cethego in 162 BC[6], there are the remains of a *villa* with a porticoed area (fig. 6), excavated at the end of the 19th century and documented in a contribution by Elter [14].

Figure 6 – *Clostris* - *Clostra Romana* in a historical photo from 1934 [AFCB[7], nn. 1031-1032].

It has already been possible to connect this place with the *statio* of *Clostris* [9, pp. 50-56 and 12][8], known in the *Tabula Peutingeriana* as part of the road route identified as the *via Severiana*. The mention of this place made by Pliny[9] in the list of places in coastal Latium between Ostia and Circeo should be considered. In this review the place is mentioned as *Clostra Romana*, next to the *fluvius Nymphaeus*. The toponym, expressed in the nominative plural in the sense of 'locks', rather than as for *Clostris* 'near the locks' (dative or ablative), has in itself the significant reference to this place as Roman. Certainly, excluding the hypothesis that this place could fall within the pertinences of *Antium* as proposed by L. Chioffi [7, p. 56 n.

[5] Reference is made to the papal reclamations of Leo X, Sixtus V and Pius VI, up to the so-called 'Integral reclamation' of the last century.
[6] Liv., *Ab Urbe* 46.
[7] Archivio fotografico del Consorzio di Bonifica dell'Agro Pontino.
[8] In this context, the discovery, within the context of nineteenth-century excavations, of an interesting epigraphic document which refers to hydraulic works carried out by one or more people, perhaps imperial prosecutors, is fundamental*: [---] l(ibertus) Phaenippus +[---] / [--- opera c]ludentium et substruc[tiones ---] / [---] de sua peq(unia) fac(iundum) cur(avit)*. See *EphEp* 8, 650; *AE* 2011, 225 and [9], pp. 53-54 (=EDR164601).
[9] Plin., *Nat. Hist*. III, 56-57.

28], it is possible, at this point, to attribute to this place an important value in the context of the definition of the borders. The mouth of the Rio Martino falls in a border area between *Antium*, *Circeii* and *Setia*, getting closer to the latter in terms of geographical distances. In the context it is also very significant that Pliny mentions *Clostra Romana* next to the *fluvius Nymphaeum* in a combination already known for other coastal sites (*lucus Iovis Indigetis* / *amnis Numicius*, *Astura flumen et insula*). The Ninfeo river originates from the sub-lake springs of Ninfa Lake and flows into the sea through the Rio Martino. The long history of the Rio Martino artificial canal becomes fundamental at this point in the relationship with the *Clostris* - *Clostra Romana statio*. The *Nymphaeum*, naturally, does not have a sufficient flow to arrive to the sea without anthropic intervention. It is interesting that its terminal section south of *via Appia*, known as Rio Martino, is the most regulated and re-excavated canal over the centuries, also used in ancient time for the water management of the locks of Fogliano Lake for fish farming and fishing activities [12]. As part of every reclamation for which sufficient documentation is available, it has been used as a water collector, preserving its functional and topographical role; in the most recent reclamation of the 1930s, it constitutes the terminal section of one of the main collectors, the 'Acque Medie' canal. The topographic position of *Clostris* - *Clostra Romana* must therefore be read in close relation with its watercourse which constitutes the waterway that allowed, overcoming the *Via Appia*, to reach the *via Pedemontana* near Ninfa and, therefore, the Lepini mountain centres (mainly *Norba* and *Setia*). The Plinian definition of '*Romana*' could at this point be connected to the definition of a 'limit of roman control', starting from the period following the conquest of Latium, also considering that *Setia* constituted the last Lepine outpost before the Volscian city of *Privernum*. It is no coincidence that even in the most recent changes of ownership (Tuscolo, Frangipane, Caetani families) a link between the Fogliano area and the mountain and piedmont hinterland is maintained.

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THE EXPLORATION OF THE COASTS OF PERINTHOS: WHAT DOES THE MULTIBEAM BATHYMETRY SURVEY TELL US?

Beril Karadöller, Caner İmren, Zeynep Koçel-Erdem

Abstract: The ancient city of Perinthos (Marmaraereglisi/Tekirdag/Istanbul), where researched with a systematic multidisciplinary archaeological project were initiated by the Ministry of Culture and Tourism in 2021, has the potential to accommodate both marine and land-based multidiscipline studies in a comprehensive approach. To investigate the traces of archaeological remains, an integrated geophysical survey was designed. As part of the project, a comprehensive multi-beam bathymetry study was carried out in the city's offshore zones, while geophysical studies were carried out on land. The bathymetry study aims to model and investigate the detailed seafloor morphology of the coast of the Perinthos. The seafloor morphology modelled using high-precision data gave us a unique opportunity to investigate the mysteries of the ancient city of Perinthos. Multi-beam bathymetry data in over 1000 hectare acquired with 400 and 700 kHz central frequency sensors. Throughout the data processing procedure, the ¨International Hydrographic Organization Standards for Hydrographic Survey¨ were adhered to. Finally, morphological imagery of the seafloor was obtained. The resolution of these images, varies between 10 cm and 1 meter depending on the depth. This study is a significant contribution to the high-resolution identification of ancient cultural heritage through the multi-beam bathymetry in marine archaeological sites.

Keywords: Multi-Beam Bathymetry, Perinthos, Marine Archaeogeophysics, Thrace Capital

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Introduction

Archaeological excavations carried out for the exploration and discovery of historical artifacts hidden under the ground require a very meticulous process and take a considerable amount of time. Knowing the location and structure of buried objects not only accelerates archaeological studies but also provides the opportunity to make reliable conclusions about these objects even before excavation. In this sense, it is valuable to utilize the power of geophysics, which sheds light on archaeological studies and provides guiding results. Land-based geophysical methods used in archaeological sites have become popular today. However, there is a need for more case studies, especially for the study of marine archaeological sites. The ancient city of Perinthos has the potential to accommodate both marine and land-based studies in a comprehensive approach.

In 2022, to investigate the traces of archaeological remains in the archaeological site, an integrated geophysical survey was designed. As part of the project, a comprehensive multi-beam bathymetry study was carried out in the city's offshore zones, while geophysical studies were carried out on land. The bathymetry study aims to model and investigate the detailed seafloor morphology of the coast of the Perinthos. Accordingly, this study will be able to detect ancient remains on the seabed. It is also envisaged that the high-resolution multi-beam bathymetry study will reveal the route to the harbor, which was used as the naval base of the ancient city. All the information obtained and the surface models derived from this information will shed light on the diving studies to be carried out at sea.

Historical Background

The ancient city of Perinthos on the coast of the northern Propontis (Marmara Sea), located in the Marmaraereğlisi district of Tekirdağ province, is undoubtedly one of the most important Thracian settlements (Figure 1). It is an important harbor settlement, and the capital of the Thracian Province during the Roman period. It has been continuously inhabited from antiquity to the present-day.

Figure 1 – Overview of Perinthos.

Being inhabited since prehistoric times, being declared the capital of the Thracian Province during the reign of Emperor Claudius in 46 AD, being in the focus of the attention of Roman emperors such as Hadrian and Septimius Severus, its convenient harbors, being located at the beginning of important road networks of the Roman Period such as Via Egnatia and Via Militaris (Via Diagonalis) and the unique opportunities provided by its geography have made the city stand out in many respects [12].

The city, which was renamed Herakleia in 286 AD during the reign of Emperor Diocletian as a reference to both Heracles, who was accepted as a ktistes and had essential cult in the city, and his ruling partner Maximianus Heraclius, consists of the acropolis, the lower city (today's modern settlement), necropolis areas and two large harbors, east and west (Figure 2). Except for the acropolis, which covers a huge area (approximately 1.5 km in length and 500 m in width) and where the buildings are mostly buried, most of the ancient city is under the Marmaraereğlisi district. The city, which has seen many remarkable periods, events, invasions, and destruction throughout history, has been under the influence of prehistoric communities, Thracian, Greek, Persian, Roman, and Byzantine cultures, and has been severely damaged by Avar and Bulgarian raids and many earthquakes [5] after the Late Antique Period.

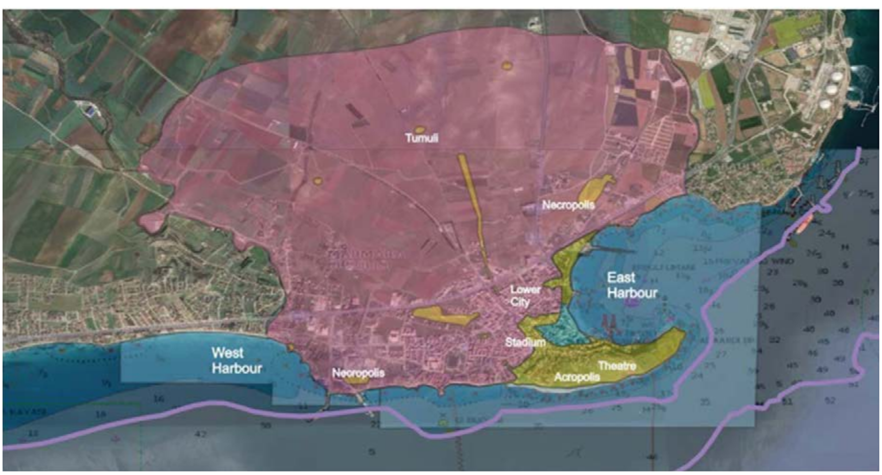

Figure 2 – Overview of Perinthos, main elements of the city.

Although Perinthos is accepted in ancient sources and scientific literature that it was founded by Samos colonists around 600 BC [12], several Prehistoric Age finds in the form of ceramics and stone tools recovered during the excavations started in the acropolis of the city in 2021 have made it possible to trace the settlement to much earlier periods [9]. The city became quite magnificent during the Roman period and became an important episcopal center during the Christian era.

Archaeological Investigations

Although the Perinthos has been mentioned many times in different aspects by ancient writers, no long-term scientific excavations have been carried out so far, except for the short-term research and soundings of Dr. Nuşin Asgari in the 1980s and the rescue excavations carried out by the Tekirdağ Archaeology Museum [1][2][3][4]. Partially surviving buildings and parts of buildings from the ancient city: The parts belonging to the land and sea walls surrounding the city from the west and north, the theater, the stadium, the basilica, the wall fragments of the Late Antique Period buildings on the Acropolis, the large vaults that could be the substructure of a monumental building, the necropolis areas and the breakwater remains of the harbor to the east of the city. The modern neighborhoods and houses located on the northern slope of the acropolis, overlooking the lower city, are positioned in a way to follows the ancient plan scheme and street patterns. On the walls of the houses, it can be seen that there are many reused materials such as inscriptions and architectural fragments. In addition, Rahmi Özcan Boulevard, the main street of the district, should be the main street of the ancient city extending from the lower city to the Acropolis. Other remains of the ancient city structures include architectural fragments, inscribed bases and tombs from various periods exhibited in the Municipality Park (Open Air Museum), and in front of the Municipality Building, as well as numerous artifacts preserved in the Tekirdağ Archaeology Museum.

The first investigations at the settlement were carried out by Cyriacus of Ancona in 1444. Various Western explorers and researchers who visited the city in the last century published several publications, mainly on honor inscriptions and some architectural and plastic works [12]. The first scientific studies that yielded significant results on the archaeological potential of the ancient city were carried out by the Istanbul Archaeological Museums. During the 1980s, Dr. Nuşin Asgari, topographer Adnan Şakar, and the Tekirdag Museum prepared a topographical plan of the city, made soundings in the stadion structure, and examined various points of the settlement and the tumuli in the north [1][2][3][4]. The most comprehensive research on the city so far is the study initiated by Prof. Dr. M. H. Sayar within the scope of a doctoral study and later published as a monograph, which sheds a great deal of light on both the history and cultural assets of the city and the history of the region in the light of Greek and Latin inscriptions [12]. In addition to this monograph, the publication of the Kapıkale Basilica in the lower city, which was excavated by the Tekirdağ Museum between 1992-2010, provides valuable information on the Late Antiquity of the city [11].

The new period of excavations in the ancient city was started in 2021 by Mimar Sinan Fine Arts University with the official permission of the Presidential Decree of the Republic of Turkey and the General Directorate of Cultural Heritage and Museums of the Ministry of Culture and Tourism. In this part of the acropolis facing the western harbor, fortifications (western walls) encircle the hill from the west, almost as a retaining wall. The walls of the polygonal tower of the fortification wall were uncovered during the excavation at the western end (Figure 3). However, it was found that the area, in general, had deteriorated considerably in the 6th century and onwards, and many courtyard spaces and workshops, which were organized for different needs, were found against the tower wall.

Figure 3 – Western excavations, walls of the tower.

Figure 4 – The largest theater in Eastern Thrace.

In the 2022 excavation season, the excavation of the theater, an important public building of the ancient city, was also started. Measuring approximately 140 x1 10 m, it can be compared with the great theaters of Anatolia and is the largest theater known in eastern Thrace (Figure 4). The Greek theater-type building, which is located on a hillside overlooking the Propontis landscape, is quite magnificent even though the cavea seating rows are not in place today. In the 4 trenches opened at the intersection of the cavea and the orchestra within the scope of the excavation, a very dense fill flowing from the upper levels was encountered, some fragments belonging to the seating rows started to be unearthed (for more information see [9][10].

Multi-Beam Bathymetry Survey

Multi-beam bathymetry is a method for measuring the depth of the seabed. It uses high-frequency sound waves sent from the sea surface to the seabed in a beam. This method quickly scans large areas of the seafloor, providing detailed information about the seafloor morphology. The temporal depths obtained in the collected bathymetry data are converted into depth information using the water column velocity. One of the most crucial aspects of bathymetry is the position of each ray reflected from the seafloor. To accurately determine the position of each reflected sound wave, we used GNSS (Global Navigation Satellite System) receivers mounted on the ship. These receivers provide precise geographical location information for the collected data.

Throughout the study [6], we utilized a boat, an unmanned surface vehicle, a bathymetry sensor, a sound velocity profiler, and GNSS receivers (Figure 5). To ensure the precision and achieve sub-centimeter accuracy of the data, we used a post-processed kinematic system. Initially, we established a local GNSS station (base) to obtain highly accurate position and elevation data, which communicated

Figure 5 – Multi-Beam Bathymetry Equipment.

with both local stations in the region and the antennas mounted on the surface vehicle. Additionally, we conducted daily sea level measurements and static measurements at the base point.

The bathymetry study was performed in two phases: shallow and deep areas. The data collection area has varying depths, and the coasts contain rocky areas. For this reason, to collect data from very shallow areas where the boat cannot reach, we used an unmanned surface vehicle (USV). The bathymetry sensor was mounted on the boat in areas deeper than 5 meters and on the USV in areas shallower than 5 meters. Calibration was performed after each installation of the bathymetry sensor on the surface vehicles. A 400 kHz signal was used as standard during data collection, and a 700 kHz signal was used for more detailed mapping of some detected objects. 1024 beams were sent to the seabed and the ping rate was taken care not to go above 20 Hz. The swath angle, the angle between the most distant beams, was variably adjusted between 120 and 160 degrees during the study to account for changes in seafloor depth. Wider angles were used in shallow areas to maintain data resolution, while the angle was narrowed in deeper areas. In rocky areas posing risks, the bathymetric sensor was digitally rotated to port or starboard to see obstacles from a greater distance.

Since the water is a non-homogeneous medium, the speed of sound varies with depth due to changes in temperature, pressure, and salinity conditions. To determine the variation of sound velocity with depth in the water column, we used a Sound Velocity Profiler (SVP). The detected velocities are used to convert temporal depths in the bathymetry data into metric depths. For this reason, we conducted relevant sound velocity measurements at specific intervals in the area. The vessel remained motionless during this process to ensure sending the device as perpendicular as possible to the seabed.

In the course of the study, we collected bathymetric data for over 1000 hectares of marine area around the ancient city of Perinthos (Figure 6) [6][7][8]. The seabed depth in the collected data varied from 40 cm to 100 meters. The data was processed using "Qimera" software, starting with positional corrections known as "patch" tests, using the calibration data obtained during data collection. It is used for roll, pitch and heading corrections (Figure 7). These corrections aimed to eliminate mismatches between profiles caused by the vessel's motion. Following that, required corrections for water velocity were applied. Both automatic and manual corrections were also made to the data to remove effects such as schools of fish and scatterings. Throughout the process, the International Hydrographic Organization Standards for Hydrographic Studies were adhered to.

As a result of a multi-beam bathymetry survey, which was launched to explore the high-resolution seafloor morphology off the coast of Perinthos, morphological imagery of the seafloor was obtained. The resolution of these images varies between 10 cm and 1 meter depending on the depth. Thereby, the anomalies on the seafloor were detected through changes in the sea bottom morphology, and both natural formations and archaeological remains were observed [7][8].

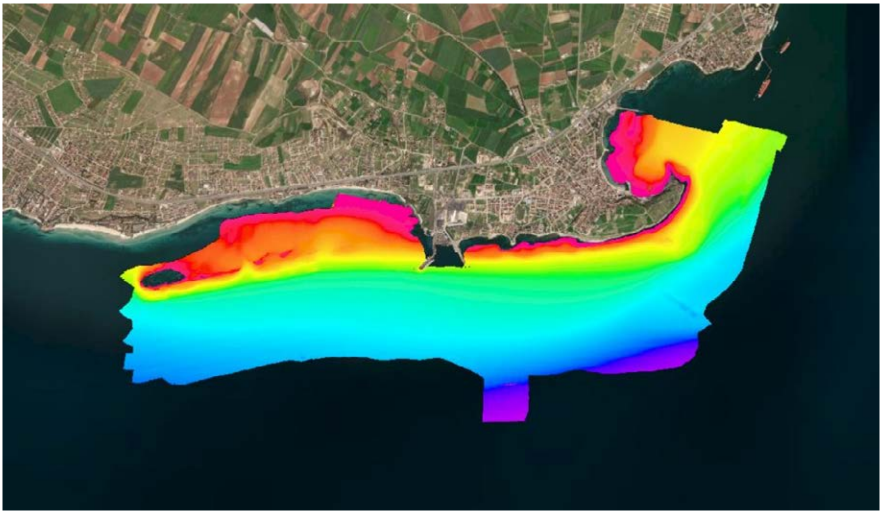

Figure 6 –Collected Data by Multi-Beam Bathymetry (Colors indicate the depths).

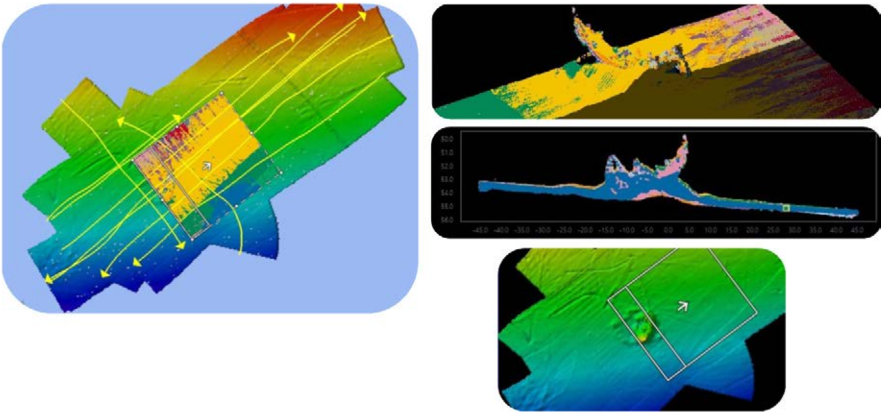

Figure 7 – Exemplary image for Multi-Beam Bathymetry Data Processing on Qimera.

Results, Conclusion and Discussion

As part of the study, an area of more than 1000 hectares was surveyed and started to be modelled with precision. Thanks to this work, unburied objects of different depths and different sizes on the seabed are detected. One of the most remarkable discoveries in the region is a shipwreck found 1500 meters off the coast of the city at a depth of about 60 meters (see Figure 7). Further studies on this shipwreck are ongoing. As a preliminary finding, it can be concluded that the shipwreck, which looks structurally different from modern boats, has a length of 25 meters and a width of 10 meters.

Another finding is a cylindrical trench with a maximum elevation difference of 5 meters from its surroundings and a width of approximately 200 meters. This trench structure is in harmony with the area that is thought to have been a harbor during the Roman Period due to its location and extension. It is likely a natural formation and may have functioned as an entrance through which people of that period passed to access the navy bay in the form of a lagoon. This situation is also handled meticulously.

Surrounding the breakwater in the eastern harbor, which was submerged by the sea level rise, various bathymetric anomalies were observed. A dive in the eastern harbor, where the anomalies observed, revealed for the first time the remains of a wall adjacent to the breakwater at a perpendicular angle. The large number of amphora fragments observed in front of this wall suggests that this area must have functioned as a dock.

The present study demonstrates the significance of using high-resolution multi-beam bathymetry to identify ancient cultural heritage in marine archaeological sites. It is essential to use geophysical methods to explore the archaeological city of Perinthos. Furthermore, a detailed examination of the marine part is crucial in addition to the studies conducted on the land parts of the ancient city.

We believe that conducting a sonar survey in addition to this study will be beneficial for detecting and visualizing archaeological remains on the seafloor. It is also critical to detect large objects such as shipwrecks, which are buried under the seafloor and cannot be seen by diving or bathymetry survey, especially considering sedimentation in marine environments. For this purpose, the study should be further supported by geophysical methods such as sub-bottom profiling methods, which allows the investigation of several meters below the seafloor.

Acknowledgements

We would like to thank the General Directorate of Cultural Assets and Museums of the Ministry of Culture and Tourism of the Republic of Türkiye, which provided the necessary permissions for the studies in the region; Mimar Sinan Fine Arts University, which undertook the patronage of the archaeology studies of the project; Istanbul Technical University, which supported the Geophysics studies of the project with the general research project number MGA-2022-43758; Marmaraereğlisi Municipality for their support; TCSG88 Command valuable personnel; Botaş LNG Operation Directorate and its valuable employees; SAMUS company and its valuable employees for being the technical sponsor of this study and supporting the study with its equipment and technical team; and finally, QPS company for donating Qincy, Qimera and Fledermaus software for this project.

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COASTAL CULTURAL LANDSCAPES OF THE TONNARE OF SOUTHEAST SICILY: ANALYSIS AND VISUALIZATION OF DATA

Leopoldo Repola, Justin Leidwanger, Elizabeth Greene, Fabrizio Sgroi, Vincenzo Morra

Abstract: The study currently underway along the coasts of south-eastern Sicily, born from the collaboration between the Federico II University, Stanford University, Brock University and the Soprintendenza del Mare della Regione Siciliana, reflects the primary stages of a research methodology focused on the analysis of spaces, both architectural and natural, in relation to the processes of use that have occurred over time. Activities have included an initial phase of 3D digitization using laser scanning, drone Lidar, and terrestrial and underwater photogrammetry of the tonnare of Capo Passero, Marzamemi and Vendicari, as well as the areas of Punta delle Formiche and Morghella in the municipality of Portopalo di Capo Passero. The data were processed to support subsequent geospatial analysis. The georeferenced models can provide an accurate representation of built heritage, settlement traces along the coastline, submerged archaeological features, and geomorphological characteristics of the area, which reflect the dynamics of landscape use and the continuous transformation of these spaces as a result of natural and anthropogenic actions. This integrated work supports new forms of communication of scientific data, both through temporary "pop-up" exhibitions, and through a planned immersive installation project in the Magazzini and in the Tonnara Tower of Vendicari, and through the study of complex spatial interrelations of the integrated data using ArcGIS Modelbuilder.

Keywords: Tonnare, digital survey, representation, underwater archaeology, architecture

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Leopoldo Repola, Justin Leidwanger, Elizabeth Greene, Fabrizio Sgroi, Vincenzo Morra, *Coastal cultural landscapes of the tonnare of southeast Sicily: analysis and visualization of data*, pp. 636-647, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.55

Introduction

Tonnare are complex architectural organisms insofar as they follow their own life over time, having been built and transformed alongside changing fishing techniques and processing of the catch. These structures possess a unique relationship with the coast on which they stand, linking the waters of the sea to the rock on dry land. These architectural spaces connect, almost without limit, the seabed and the land in a continuous transition. Here we understand the intimate relationship between nature and artifice, between function and ritual, between an architecture that stands on the edge of the sea and one that continues into the depths by means of nets and anchors. These complex buildings, crafted of stone on land find their essential counterpart in the sea: the *madraghe*, the net chambers for catching fish [10]. By necessity, tonnare were built close to promontories to better observe the tuna routes; their bays sheltered boats used during fishing periods; their rocky shores offered quarries for blocks necessary to construct buildings and to tie the nets to the seabed and the rope of the *pedale*; their lagoons produced salt for processing the catch; their sandy bottoms prevented damage to the *isula* nets during storm surges. The tonnare on water and land constitute a single building: they have a single name and like an amphibious organism they must respect the laws of sea and stone.

This research project explores the characteristics of these complex architectures, tracing their recurrence and modifications across the layered histories of this corner of Sicily. Along the coastline between Punta delle Formiche in the municipality of Pachino and the Vendicari Reserve in the municipality of Noto, five places follow one another, preserving to different degrees the signs of structures of fishing and tuna processing. Architecture, archaeology, and nature come together in these five landscapes defined by the coexistence of events, histories, persistence and profound transformations. Our explorations include the tonnara of Vendicari (fig. 1) used in

Figure 1 – View of the Vendicari tonnara taken by drone.

the past as a harbor-dockyard and now part of the Nature Reserve; the abandoned tonnara in the center of Marzamemi [3] partly renovated for commercial and tourist uses today; the small promontory of Morghella, which probably housed an ancient tonnara later replaced by that of Capo Passero [1], whose buildings are in a poor state of preservation due to long periods of disuse; and Punta delle Formiche, where signs of the presence of an ancient fish processing plant are clearly visible.

Technologies and processes for studying tonnare

Our research aims to integrate the spaces of these installations on land and in the sea. This innovative spatial approach begins from three-dimensional digitization of the seabed, considered alongside the technical systems of the *madraghe*, the orographic contexts, and the architectural structures related to tuna fishing. Through the combined use of various systems for the acquisition of 3D data, such as the phase shift laser scanner Faro Focus S70, DJI Phantom 4 Advance drone, GoPro Hero 10, Nikon D70, and the ISU3D prototype system [9], continuous models of portions of the coastline, architectural structures and submerged areas have been produced and georeferenced. These ongoing activities have focused primarily on the area of the ancient port of Vendicari, where 3D digitization procedures have been carried out in tandem with archaeological investigation on an area of approximately 400 square meters. Within this area, a series of ballast piles may reflect the activities of fishing boats and merchant vessels (fig. 2) [6] [7].

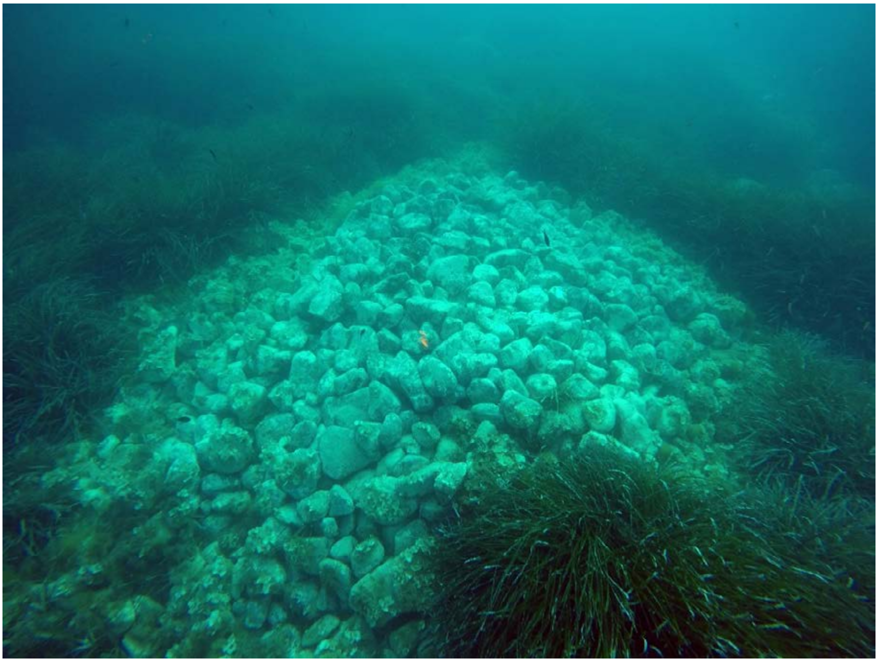

Figure 2 – Ballast found in Vendicari.

In 2023, three-dimensional digitization procedures were carried out using photogrammetric and Lidar drone systems of a large area of the Vendicari Reserve (fig. 3) aimed at understanding the long-term transformation of this fragile natural environment: wetlands, riverbed, coastline, bay, and islet.

Figure 3 – Lidar survey phases by Drone Matrice 300.

Survey activities also covered the structures of the tonnara, the warehouse buildings and the ancient tower in order to produce a high-resolution textured model obtained by integrating Lidar data with point clouds generated by terrestrial and aerial photogrammetry. Future integration of local environmental data (e.g. average rainfall indices, wind intensity, wave analysis) will allow the documentation of ongoing silting and erosion phenomena on different types of coastline, to verify the retreat or advancement of wetlands, and to monitor the surface alterations of the blocks and mortar of the architectural structures in relation to their orientation and proximity to the sea. In the same year, a bronze helmet from the early modern age was found on the seabed under investigation, which is currently being restored, adding a further layer to the continued use of the port beyond antiquity (fig. 4).

The area of the discovery was surveyed using photogrammetric procedures to map the wooden elements that were probably brought to the surface by a storm surge (fig. 5). The models revealed a possible shape of the wreck and the presence of numerous ceramic artefacts, probably part of the ship's cargo or ship's furnishings (fig. 6).

Figure 4 – The helmet at the moment of discovery.

Figure 5 – Survey activities of the helmet discovery area.

Figure 6 – 3D model of the seabed with location of wooden parts of the wreck.

Elements of this approach to an integrated study of the tonnare and their landscape have also included survey and recording beyond Vendicari. In 2019, a 3D survey of the tonnara of Marzamemi was carried out alongside initial survey in the associated harbor. Here, a number of large stone blocks (1.20 x 0.70 x 0.50 cm) were recorded depth of 9÷16 m; two large anchors discovered nearby would suggest the geometrical layout of a *madraga*. Underwater survey off the Island of Capo Passero in 2020 also yielded the discovery of a large anchor and various stone elements (fig. 7) at a distance of about 3 km from the coast and a depth of 22÷35 m.

Figure 7 – A block and an anchor from the tonnara off the island of Capo Passero.

Figure 8 – Textured point cloud of the Capo Passero tonnara.

The known location of the attachment point of the *pedale* on the east side of the island will facilitate future work to fix the location of the *madraga* and *pedale* and the associated activities of the tonnare in the sea. Surveys of the seabed were followed by 3D digitization activities, through images acquired by drone and processed using Metashape and 3DF Zephyr software, of the entire island of Capo Passero and a limited portion of coastline south of the beach of Scalo Mandrie di Portopalo. The tonnara buildings still present on the island and the historic boats used for the *mattanza*—two *muciare* and one *sciere*—were surveyed with millimeter resolution using a Faro Focus S70 laser scanner. These models were aligned to the island model and imported into the larger georeferenced spatial model. The surveys of the area continued in 2022 with the digitization of the entire tonnara on land using drone photogrammetry for the exterior parts of the buildings and areas in a state of ruin, and Faro laser scanning for the interiors. The processed models were aligned using scalebars and imported into the georeferenced spatial model (fig. 8).

In 2021, photogrammetric drone surveys were carried out of the saltworks, tanks, and quarries in the Morghella area in order to verify the functional relationships between the saltworks and the possible tonnara on the coast.

At the saltworks, a low promontory, about 6 m high, juts out into the sea for about 130 m from the bay of Morghella. Along the southeastern side are evident the entrances of two possible canals (the submerged one to the south may be the more ancient), a *latomia* or quarry area, and rectangular-shaped basins sloping into the water (fig. 9).

In order to confirm the presence in this area of a tonnara predating the eighteenth-century installation at Capo Passero, further detailed recording of shore and adjacent waters using drones, diver reconnaissance, and multibeam survey are planned. Aerial photogrammetric recording of the Punta delle Formiche site, where numerous elements attributable to a Roman fish processing plant are clearly recognizable [4] promise to yield parallels to quarrying, construction, and production processes connected to the structures on land and sea at Morghella. The numerical model was managed and segmented to identify quarry areas, basins, ordered series of holes for different types of bollards (0.20-0.30 m in diameter), docking area for boats, and a tuna sighting post (indicated by two holes connected by a deep cut) (fig. 10).

Figure 9 – Orthophoto with characterization of the areas of the Morghella promontory. Area 1: latomia; point 2: oldest canal; point 3: most recent canal; area 4: recent quarry.

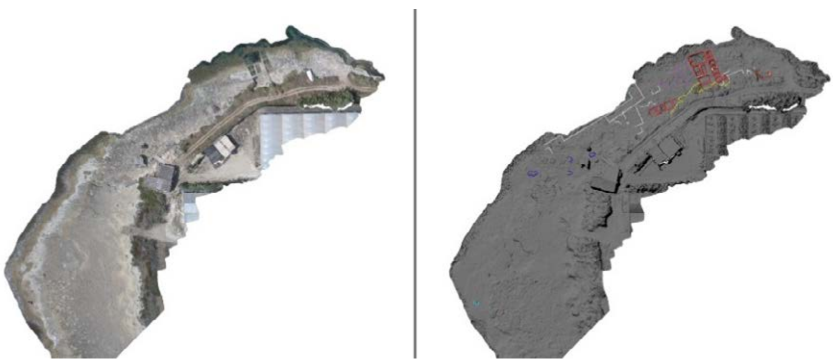

Figure 10 – Two views of the model, textured and in grey tone, of the Punta delle Formiche site showing the traces engraved in the rock. Red: basins; Magenta: holes; Blue: bollards; White: geometries; Light blue: specula; Yellow: rock.

The digital models of these elements and their spatial relationships form a primer of typological elements that will inform spatial analysis of the Morghella models and their application to data from other less well-preserved sites. The models of Morghella and Punta delle Formiche will be integrated with underwater surveys adjacent to the coastline of the two sites, in order to generate continuous models of the visible and submerged parts of the tonnare, including architectural structures, basins, *latomie*, and *madraghe*. These features will enable study of transforming sea levels, coastal erosion, and the associated changes in the local traditions of net fishing.

Model development visualization and geospatial data management

The current research with its goal of exploring the long connection between past and present of the traditional tuna fishing activities in southeast Sicily, builds on earlier projects undertaken by this team, including archaeological excavation of the famous late antique “church wreck” at Marzamemi and the value of cultural heritage as a means of fostering public understanding of the many connections made possible by the sea [5] [11]. Designed to link archaeological research on the island’s maritime past with modern debates over development, overfishing and the loss of intangible heritage, and migration, the exhibit, *Attraverso il Mediterraneo | Through the Mediterranean* provided a walking itinerary across the local landscape of Portopalo di Capo Passero. In coordination with local officials, we exhibited three boats around the municipality, creating a walking tour for visitors.

Reflecting the sea’s role in economic interaction the Marzamemi "church wreck" offered the starting point along the main street, marked by cafes, restaurants, civic offices, and businesses. A mattanza boat replica offered historical context for three historic tuna fishing vessels already displayed in an adjacent piazza; the exploration boat sat on a point overlooking the sea, offering visitors the chance to imagine themselves navigating by the stars to traverse open waters in search of new shores. The boat geometries were supplemented with imagery, video, sound and a brief informational text panel in Italian and English. To cite just one example of the mattanza boat, the digital content reproduced during the exhibit rendered various moments of the mattanza, the songs, the gestures of the fishermen, the *scieri* and *muciare*, the sea rippled by the tuna caught in the nets, the chimneys and vats of the tonnara, within an ephemeral space extracted from the iconic shapes of boats that recall the cultural landscape of these places, where the sea and the land come together in the tools of work (fig. 11). With its creative staging, this pop-up exhibit of voats engaged local viewers with the long term histories of the sea.

Figure 11 – Exhibition in the Marzamemi square.

This work plan also defined a first step for the production and optimization of multimedia content for the more ambitious project of creating a Museum of the Sea inside the historic Palmento di Rudinì in Marzamemi, as imagined together with

Sebastiano Tusa [12]. This building was the subject of an initial valorization hypothesis, in which, through the use of parametric modelling procedures using Grasshopper software, several reconstructive hypotheses were proposed for the architectural elements from the Marzamemi "church wreck" (fig. 12).

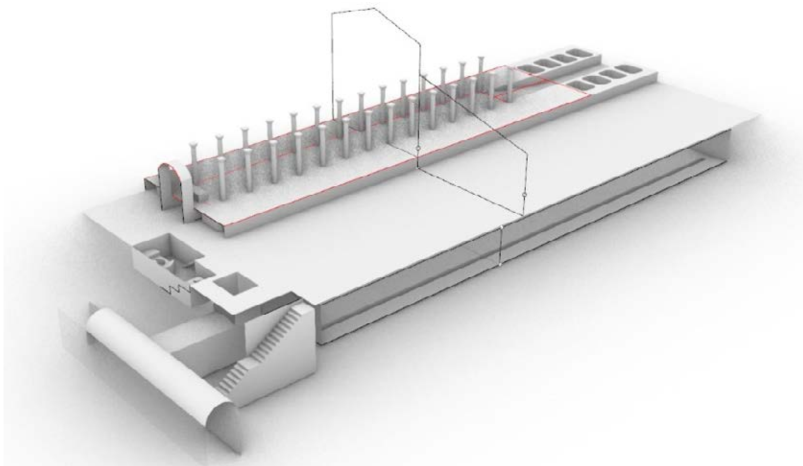

Figure 12 – Study model of the exhibition inside the Palmento.

3D models of the Palmento's architecture allow for proposed exhibits in both the main floor's basilica-like plan, and the spaces of the underground cisterns in which immersive installations might represent the events of the ancient shipwreck. This hypothesized path offers a framework in which real and virtual data define narrative scenarios for public storytelling [2] [13].

With the same objective of enhancing and communicating the knowledge obtained through field research activities, a musealization project was launched in 2023 in agreement with the Vendicari Nature Reserve, the Superintendency of the Sea, and the Superintendency for Cultural and Environmental Heritage of Syracuse, to transform the Vendicari storehouses and tower as spaces for storytelling. With light and reversible interventions in these important structures, along with digital technologies, the exhibit aims to include 3D models of the heritage surveyed, and narrative videos of maritime life and coastal change on land and underwater. The valorization plan includes two primary goals:

- To install, in the warehouse building next to the Ecomuseum Library, a multimedia installation by means of video documentaries and animations concerning underwater research, tonnare, ancient Mediterranean routes, and marine biodiversity. The installations will include immersive video- and audioscapes for viewers that draw from archaeological, historical, geological, natural, and ecological investigations at Vendicari. The exhibition plan includes a graphic design to which illustrative and didactic panels will be connected on the southern walls of the two rooms.

– As a second phase, we aim to install in the tower an exhibit aimed at representing the historical sequences of Vendicari Bay and the stratigraphic complexity of its seabed and coastline. The project intends to create a visitor route from the steps at the side of the entrance to the terrace. Infographics on glass and multimedia content, which can be visualized using augmented reality apps, will represent the points in the sea where wrecks and artifacts have been found, as well as the geological transformations of the area from prehistoric era to recent times. Going down the steps inside the tower, it will be possible to experience immersive video mapping and soundscapes that will narrate the research on the tonnara at sea, the wrecks, the anchorages, and other signs of historical use of the bay and the extended area surrounding Vendicari. The narration will be linked to an exhibition of archaeological finds from these waters.

The second management strategy is aimed at harnessing digital data in the development of an advanced data management system in a three-dimensional simulation environment where multi-level data and interoperable numerical models converge. The aim is to devise a tool for interpolating data from multiple scientific disciplines, in order to graph and execute complex interrelations in the progressive development and long-term transformation of the maritime landscape of the tonnara. The architecture of this GIS platform will allow the use of exchange diagrams between textual data, images and models, towards SIM (Spatial Information Modeling) visualization environments [8] to support the segmentation and analysis of geo-spatial data (fig. 13).

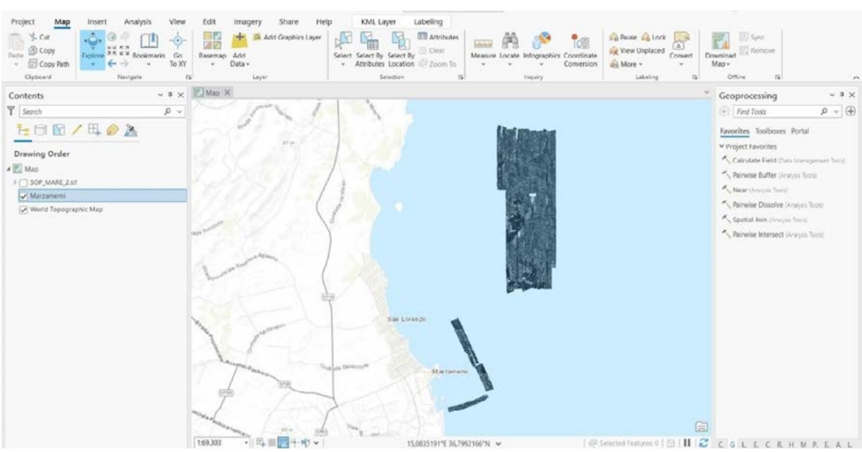

Figure 13 – GIS platform interface.

Conclusion

The survey of the buildings and traces of ancient installations on the rocks near the sea, the 3D digitization of the sequences of blocks and anchors still lying on the seabed, their origins and dating by means of petrographic and biological investigations, the study of the geological transformations of the coast (also due to calamitous events like earthquakes), the variation of the sea level with the relative transformation of the seabed, and the evolution of fishing and fish preservation techniques (including the shifting socio-economic relationships within communities), composed interrelated information layers using tools such as ArcGIS Pro's ModelBuilder. These visual programming tools for the construction of geoprocessing workflows will allow for the automation of spatial analysis and data management processes. Through the integration of diverse data collected from archaeological recording, historical research, ethnographic interviews with local fishermen, aerial and LIDAR data, and records of coastal erosion and transformation, we seek to build a more complete understanding of the coincidence of contextual, historical-cultural and technological conditions which have influenced the shapes, sizes and location of the tonnare over time.

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THE BUILDING MATERIALS OF THE LORENESE FORTS OF THE TUSCAN COAST

Silvia Rescic, Fabio Fratini, Manuela Mattone

Abstract: This work examines the natural and artificial stone materials (mortars and bricks) used in the construction of the fortifications realized by the Grand Duke of Tuscany Pietro Leopoldo between 1786 and 1793 along the Tuscan coast. The aim is to verify the possible relationship between the materials used and the stone resources and raw materials (clays for bricks and limestone for the production of lime) of the individual territories, or to ascertain a standardised use of materials, with origin from a single production centre. Furthermore, the state of conservation of these fortifications in relation to decay phenomena will be examined, trying to highlight the influence of environmental factors and the characteristics of the stone materials.

Keywords: Lorenese Forts, Tuscany, Grand Duchy of Tuscany, Building materials

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Introduction

The system of fortifications along the Tuscan coast is made up of 160 structures, including fortified centres, individual castles, watchtowers and buildings for the residence of soldiers and guards. Built from the Middle Ages, by the mid-14th century the castles, towers and military posts formed a relatively dense and effective network. In the 16th century, an exceptional increase in piracy along the Mediterranean coast necessitated the reorganisation and reinforcement of the coastal defence system in response to changing offensive techniques. Thus, between the 1630s and the beginning of the 17th century, numerous turreted and bastioned fortifications were built, proposing innovative architectural and technological solutions.

During the 18th century, the European Wars of Succession and the Seven Years' War led to a further strengthening of the Tuscany fortified system: fifty new structures were built and, in 1739, a military genius was appointed to survey, restore and strengthen the existing structures. In particular, under Pietro Leopoldo, six new forts were built along the coast between 1786 and 1793 to protect Tuscany from the threat of pirates and to combat smuggling [1-9]. All of the forts are of the same type, with a quadrangular body and an adjoining semi-circular platform on the sea front: *Cinquale nuovo*, *Forte dei Marmi*, *Marina di Bibbona*, *Marina di Castagneto*, *Marze* and *San Rocco* (Fig.1).

Figure 1 – Localisation of forts (from Google Earth Pro V 7.3.4, (10 April 2013), data Landsat / Copernicus Data SIO, NOAA, U.S. Navy, NGA, GEBCO,43°44'27"N 10°50'47"E, camera 293km, modified [10]).

These forts, except for the one at *Cinquale Nuovo* destroyed during the Second World War, have all been preserved. Some of them have been restored by private and/or public administrations, others are in a state of neglect.

This work examines the natural and artificial stone materials (mortars and bricks) used in the construction of these fortifications. The aim is to verify the possible relationship between the materials used and the stone resources and raw materials (clays for bricks and limestone to produce the lime) of the territories, or to ascertain a standardised use of materials coming from a single production centre. Furthermore, the state of conservation of these fortifications in relation to decay phenomena will be examined, highlighting the influence of environmental factors and the characteristics of the stone materials. In the following, historical and architectural information about the forts will be given together with a concise description of the construction materials and their current state of preservation.

Forte San Rocco

The fort of San Rocco is a coastal fortification in the municipal territory of Grosseto, in the town of Marina di Grosseto. The complex was built by the Lorraines in the second half of the 18th century, where a pre-existing structure with sighting functions had been erected [9]. The new fortress continued to play an important role in coastal control and became a logistical base for hydraulic reclamation works in the area. Upon completion of the canal works, which led to the draining of the ancient inland marshes and historic Lake Prile, the building was converted into a military district. After the annexation of Tuscany to the Kingdom of Italy, the fort was used as barrack for the Guardia di Finanza. Currently it is totally abandoned. Originally built facing the sea, today it is about 500 meters from the shoreline. It consists of three distinct structures: the bastion facing the sea, the central tower-building with four slopes, and the courtyard at the back, protected by a wall (Fig. 2a). The rampart consists of a mighty scarp of masonry 10 meters high and 2.60 meters thick at the base and topped by a large terrace that housed artillery.

The three structures are clad in bricks: larger those of the rampart (dimensions of 28x 17 x 8 cm), shaped to have a smooth surface toward the outside, and set with thin mortar joints (0.5 cm thick); smaller the ones of the central tower and courtyard wall (dimensions of 25 x 12.5 x 4 cm) laid with thick mortar joints. The base of the rampart consists of a plinth in Pietra Panchina [11], which is also found in the stringcourse frame of the rampart itself and in the opening frames of the tower building. The jambs and the pointed vault of the access to the rear courtyard are in organic limestone. Nowadays, the building is abandoned. A restoration of the masonry was carried out adopting pinkish mortar to reintegrate brick gaps. In the rare places where the mortar fell, the bricks are affected by honeycombing (Fig. 2b). This phenomenon is also present in some of the bricks of the central tower and the courtyard wall, sometimes totally eroded. In addition, the masonry of the north-east courtyard wall is completely covered with lichens.

a

b

Figure 2 – Forte San Rocco (a); particular of the alveolisation phenomena that have completely eroded the bricks (b).

A further issue is the severe erosion of the mortar joints, especially on the south-east façade. The Pietra Panchina of the bastion kerb and the stringcourse cornice are in good condition. The marble coat of arms is well preserved but it is affected by a reddish discolouration probably due to lead oxide from the coat of arms' anchoring pins.

Forte delle Marze

The Marze fort is in the municipality of Grosseto, along the road that connects Marina di Grosseto to Castiglione della Pescaia. It was built in the second half of the 18th century as seawater lifting plant and accommodation for the managers of the new saltworks commissioned by the Lorraines. The grand new salt plant was located between the tombolo and Lake Castiglione in the area known as 'Marze' replacing that of Trappola, too exposed to the floods of the Ombrone river that almost annually covered the basins with mud. Although the Marze fortress did not originally have a defensive function, in 1792-93 it was adapted as a fortress by the Grand Ducal architect Pietro Conti and included in the coastal defence system. After the annexation of Tuscany to the Kingdom of Italy, the fort housed a garrison of the Guardia di Finanza [9]. After its decommissioning, the fort rapidly decayed. Around 1925, the state property granted it to private owners who carried out renovation work becoming a dwelling whose original function is difficult to identify.

The building is located at the back of a low coastal dune, about 20 metres from the shoreline. The complex is composed by two adjoining buildings. The first consists of a bastion facing the sea, with a scarp at the base, above which there is a terrace covered by a loggia with a sloping roof (Fig. 3a). The second, at the rear, is a building with a square plan covered by a four-sloping roof. The rampart of the bastion, partially covered by sand, is made up of well-cut Pietra Serena sandstone ashlars. A stringcourse in the same material separates the rampart from the parapet wall, made of well-cut sandstone blocks of Pietra Bigia [12]. The crowning of the parapet is made of knife-laid bricks. The corners of the bastion are in rusticated Pietra Serena. The building behind it is made up of ashlar of Pietra Bigia on the first floor and bricks on the second floor. Pietra Bigia was also used for the columns of the loggia. The sandstone ashlars, when not protected by calcite veins, are strongly eroded (Fig. 3b). The bedding mortar joints, with a thickness of 0.5÷1 cm, generally exhibit a high degree of cohesion.

a

b

Figure 3 – Forte delle Marze (a); detail of the Pietra Serena ashlars of the bastion scarp wall (b).

Forte di Marina di Bibbona

The construction of the Fort of Bibbona is closely linked to that of the nearby Fort of Castagneto. The twin complexes were completed around 1789-1790. The building housed the premises for the guardhouse and stables serving the Cavalleggeri, who had the task of patrolling the coast along the nearby border between the Marquisate of Cecina and the jurisdiction of the Torre di San Vincenzo [9]. In 2019, the property was transferred from the State Property Office to the Municipality of Bibbona in order to make it more accessible to the public through an enhancement programme.

The fort, originally built on the sea, is now about 100 metres from the shoreline. It consists of two buildings: the bastion facing the sea, with a mighty scarp wall of about 10 metres with chamfered angles, surmounted by a large terrace that housed the artillery; and the three-storey tower-building, with a four-sloping roof (Fig. 4a). The rampart is clad in bricks measuring 30 x14 x 6.5 cm with smooth outward surface. They are walled with 1.5 cm thick mortar joints. The base of the bastion consists of a plinth in Pietra Panchina, which is also found in the stringcourse frame of the bastion itself and in the opening frames of the tower building. The tower-building is plastered, but where the plaster has fallen off, it is possible to observe that the masonry is composed of unhewn blocks of Pietra Panchina and rare bricks walled with abundant mortar.

The bricks of the south-facing bastion are often spalling and honeycombed with eroded mortar joints. In some places, particularly in the south-eastern corner, they have been replaced. The Pietra Panchina of the rampart kerb and the stringcourse cornice are generally in good condition. However, exfoliation phenomena can be observed when the ashlars are laid parallel to the surface of the masonry (Fig. 4b). Some replacements and cement additions are also evident.

a b

Figure 4 – Forte di Marina di Bibbona (a); particular of exfoliation phenomena caused by improperly installed Pietra Panchina (b).

Forte di Marina di Castagneto

At the beginning of the 18th century, the municipal territory of Castagneto had several harbours, including the 'Renaione' (port of Bolgheri) and the 'Seggio'. Near the latter, in 1786, Pietro Leopoldo built the Fort of Donoratico (or Marina di Castagneto), followed closely by that of Marina di Bibbona. The Fort became a customs post and a reference point for exchange and shipments of goods by sea, thus bringing prestige and advantages to the northern Maremma [9]. In 1862, with the advent of the Kingdom of Italy, the fort became the seat of the Guardia di Finanza garrison and was later assigned to the Della Gherardesca family and the Municipality of Castagneto. Since July 1977, it is abandoned, although in 2019, an adaptive reuse project was approved for its redevelopment.

This fort was originally built on the sea but today is about 100 metres from the shoreline. Similarly to its twin fort at Marina di Bibbona, it consists of two buildings: the bastion facing the sea, with of a mighty scarp wall, about 10 metres high, with chamfered angles, surmounted by a large terrace that housed the artillery, and the three floortower-building, with a four-sloping roof (Fig. 5a). The rampart is clad in bricks, with dimensions of 28.5 x14 x 4.5 cm, and is walled with mortar joints approximately 1 cm thick. The base of the bastion consists of a plinth of Pietra Panchina, which is also found in the stringcourse frame of the bastion and in the frame of the openings of the tower building. The tower-building is plastered but given the extreme similarity of this fortified complex with the fort of Marina di Bibbona, it is presumable that it was built similarly, i.e., with rusticated blocks of Pietra Panchina and rare bricks walled with abundant mortar.

The bricks and the Pietra Panchina of the lower part of the bastion have been affected by graffitis. They are both very porous materials, and a cleaning operation is hardly able to remove them. Regarding natural decay, the bricks on the south-facing side of the bastion are often heavily eroded or showing spalling and honeycombing phenomena. Erosion affects also many mortar joints and there are numerous incongruous interventions such as reintegration of the joints and filling of missing bricks made with cement mortar. The part of the bastion facing north-east is covered with lichen (Fig. 5b). The Pietra Panchina of the rampart kerb and the stringcourse cornice are generally in good condition, and often the surface finish of the ashlar with ribbon and vertical grooves is still visible.

a b

Figure 5 – Forte di Marina di Castagneto (a); particular of biological growth phenomena (lichens) and brick erosion (b).

Forte dei Marmi

Forte dei Marmi was built in 1788 by Pietro Leopoldo I Grand Duke of Tuscany with the intention of strengthening the defence system of the coastal towers. The structure was also used as a marble warehouse during the period when the local pier was a commercial port, thanks to its strategic position [2-4].

The fort is located approximately 400 m from the shoreline (Fig. 6a). It consists of a bastion facing the sea, made up of a wall about 5 metres high with chamfered corners, surmounted by a large terrace and behind it a two-storey building with a four-sloping roof. The wall is faced with bricks measuring 28.5 x 14 x 3 cm. The mortar joints are about 0.5 cm thick. A base is not observed, but this may be since the current forecourt surrounding the fort is at a higher level than the original one. The stringcourse cornice and the openings of the tower building are made of white veined marble. The tower building is completely plastered, and therefore it is not possible to observe the masonry apparatus.

The building was completely restored in 2004, and it is in good condition. During the restoration work, the most decayed bricks, especially those affected by honeycombing and spalling phenomena, were integrated with a mortar imitating the bricks themselves, others were replaced, and the mortar joints were re-pointed (Fig. 6b). Some of the decayed bricks showing spalling phenomena are still visible (Fig. 6b). The marble architectural elements are in excellent condition but given the long years of exposure to weathering and marine aerosols, it is probable that they were replaced with new ones during the restoration.

a b

Figure 6 – Forte dei Marmi (a); particular of re-pointed mortar and brick erosion phenomena (b).

Materials and methods

Bricks and bedding mortar were sampled from all the forts (except for Forte dei Marmi) taking advantage of the detached fragments so as not to damage the masonry. In particular:

- Forte San Rocco: two bedding mortars and two bricks from the bastion, two bedding mortars and two bricks from the tower building;
- Forte delle Marze: two bedding mortars from the bastion;
- Forte di Marina di Bibbona: two bedding mortar and two bricks from the bastion;
- Forte di Marina di Castagneto: three bedding mortars and two bricks from the bastion.

The following investigations were carried out:

- the mineralogical composition was determined on the ground samples using a PANalytical X'PertPRO diffractometer with CuK1 = 1,545 Å radiation, operating at 40 KV, 30 mA, investigated range 2θ =3-70°, equipped with an X' Celerator multidetector and High Score data acquisition and interpretation software;
- the petrographic study was carried out on thin section (30 microns thick) observed under a transmitted polarised light optical microscope (ZEISS Axioscope. A1 equipped with a camera (5-megapixel resolution).

Regarding the mortars, there are many characteristics to investigate, such as the amount and type of binder, the grain size and composition of the aggregate, the type of lime lumps. This makes it possible to differentiate them, to confirm different construction phases and to identify new ones. Concerning the binder, the study of lumps gives information about the kind of carbonate stone that was burnt to produce the lime [13-15]. As for the bricks, it is possible to recognize the amount and kinds of framework (use of a lean or fat earth). Moreover, the mineralogical analysis through x ray diffraction gives information about the possible use of a marly clay (presence of calcium silicates) and an estimation of the firing temperature.

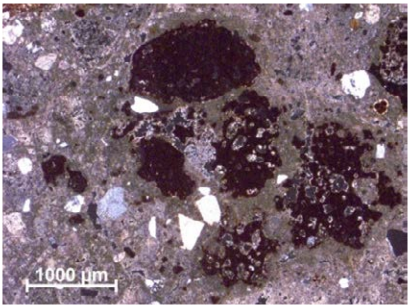
Results

Forte San Rocco

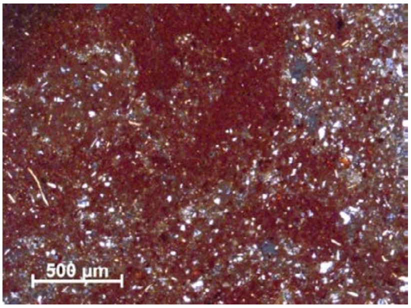
The bastion bedding mortars have an abundant to medium binder (binder/aggregate ratio from ~ 1/1 to ~ 1/3) consisting of aerial lime with a micritic appearance, hydraulicized with the addition of scarce pozzolan in both coarse and finely ground fragments. The aggregate is homogeneously distributed with unimodal grain size (200÷400 μm) and consists of subangular to subrounded granules of quartz, sparitic calcite, fragments of organogenic carbonate rocks, and feldspars. Lime putty lumps and under-burnt remnants of organogenic limestones are present. Macroporosity consists of irregularly shaped pores and shrinkage fractures (Fig. 7a).

The bedding mortar of the tower shows a medium to abundant binder (binder/aggregate ratio ~ 1/2-1/3) consisting of hydraulic lime. The aggregate is homogeneously distributed with bimodal grain size (200-400 μm predominant fraction, 1.5-2 mm secondary fraction) and consists of angular-shaped granules of sparitic calcite, marble fragments, quartz. Macroporosity is scarce and subspherical in shape.

The bricks of the bastion and tower are similar to each other. They were obtained by firing an almost pure clay. The framework is almost absent (rare quartz granules of size 200÷300 μm are present) (Fig. 7b). The groundmass is opaque, indicative of a firing temperature above 800 °C. Macroporosity is scarce and regular in shape.



a



b

Figure 7 – Images at the optical microscope in thin section, crossed polarized light: bedding mortar of the bastion with presence of pozzolan (a); brick with opaque groundmass and almost absence of framework (b).

Forte delle Marze

As reported in the description of the Forte delle Marze, the masonry is made of sandstone ashlars referable to Pietra Serena and Pietra Bigia, extensively studied materials [12]. Therefore, only the bedding mortars were studied. The mortars consist of a scarce binder (aggregate binder ratio ~1/3) of aerial lime of micritic appearance. The aggregate is homogeneously distributed with unimodal grain size (300÷400 μm) and consists of subrounded granules of sparitic calcite, organonogenic and micritic limestones, quartz, and arenaceous fragments (Fig. 8). Lumps of lime putty are present. Macroporosity is scarce and regular in shape.

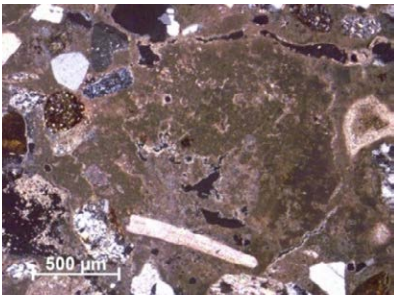
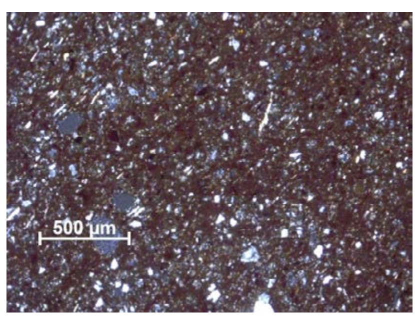


Figure 8 – Images at the optical microscope in thin section, crossed polarized light of the bedding mortar with a lump of lime putty.

Forte di Marina di Bibbona

The bastion bedding mortars have a medium to abundant binder (binder/aggregate ratio ~ 1/2-1/3) of aerial lime of micritic appearance. The aggregate is homogeneously distributed with unimodal grain size (300÷500 μm), and consists of subangular to subrounded grains of quartz, serpentinites, sparitic calcite, and micritic carbonate rocks. Numerous lumps of lime putty and under-burnt remnants of organogenic limestones are present (Fig. 9a). Macroporosity is scarce and consists of irregularly shaped pores. The bricks of the rampart are similar to those of Forte San Rocco and were obtained by firing an almost pure clay. The framework is almost absent (rare quartz grains of size 200÷300 μm). The groundmass is opaque, indicating a firing temperature above 800 °C (Fig. 9b). Macroprosity is scarce and irregular in shape.

a



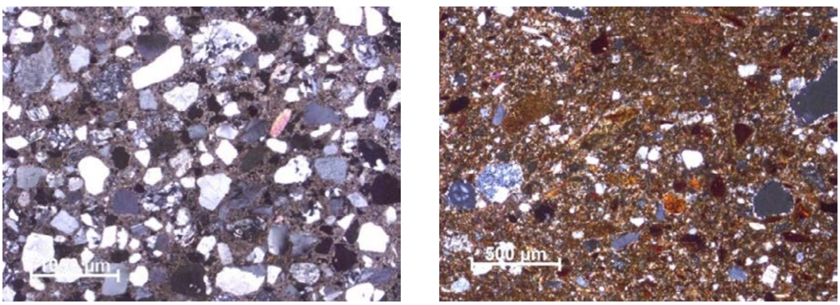
b

Figure 9 – Images at the optical microscope in thin section, crossed polarized light: bedding mortar with presence of serpentinite in the aggregate (a); brick with opaque groundmass and the almost absence of the framework (b).

Forte di Marina di Castagneto

The bastion bedding mortars have a scarce binder (ratio binder/aggregate ~ 1/3-1/4) of aerial lime of micritic appearance. The aggregate is homogeneously distributed, with unimodal grain size (300÷500 μm) and consists of subangular-shaped grains of quartz, feldspars, quartzites, rare pyroxenes (Fig. 10a). Lumps are absent. Macroporosity is poor and consists in irregularly shaped pores.

The bastion bricks were obtained by firing a silty clay as indicated by a framework made of an abundant fraction of quartz and feldspars with a size of 20-40μm. The groundmass is weakly birefringent, suggesting a firing temperature below 700°C (Fig. 10b). Macroporosity is scarce and irregular in shape.



a b

Figure 10 – Images at the optical microscope in thin section, crossed polarized light: bedding mortar with an abundant aggregate (a); brick with a weakly birefringent groundmass and abundant framework consisting of quartz and feldspars (b).

Conclusions

The study of the building materials makes it possible to relate the resources of individual territories to their use over the centuries. Indeed, buildings constructed in times when a standardised production of building materials was not yet present reveal their local identity. The Pietra Panchina, a material characteristic of the Tuscan Maremma, is present in the architectural elements of the forts of Bibbona, San Rocco and Castagneto, while in Forte dei Marmi the same architectural elements are made of white veined marble from Carrara. Also, with regard to the bedding mortars, the study of the aggregate made it possible to verify the local supply (e.g. ophiolitic grains in the mortars of the forts of Castagneto and Bibbona). As for the bricks, those from Forte di Bibbona and Forte San Rocco appear to have been made in the same production centre both because of their similar texture (almost absence of the framework) and because of their similar dimensions. while a different clay raw material appears to have been used for the bricks of forte di Castagneto.

Excluding the recently renovated forts, the others show signs of decay caused by their interaction with the marine environment. This includes the combined effects of marine aerosol and sand erosion, which can be seen in the alveolisation phenomena on the bricks. Additionally, there are other forms of decay that are a result of the forts' new environment, brought about by the retreat of the coastline. These include biological growth. Some forms of decay are also due to human activity, such as the improper installation of stone ashlars or the destructive actions of vandals who have defaced the masonry with graffiti.

It is worth noting that some recovery interventions have successfully revitalized the forts, transforming them into public spaces. This type of approach should also be applied to the abandoned forts in order to halt the process of decay caused by the lack of necessary maintenance. This would ensure the recovery, safety, and usability of the site.

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DIAGNOSTICS AND CONSERVATION OF COASTAL ARCHEOLOGICAL SITES: THE CASE STUDY OF THE ROMAN VILLA OF CASIGNANA, REGGIO CALABRIA (ITALY)

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Abstract: The conservation of coastal archaeological sites, like the Roman Villa of Casignana in southern Italy, dating back to the 4th century AD, faces various threats, including erosion, rising sea levels, and urbanization. To preserve this site's valuable mosaics, a multidisciplinary approach involving archaeology, environmental science, engineering, and community engagement is necessary. The University of Calabria, particularly through its Restoration academic course and Heritage Science research group, focuses on conserving and valorizing the Villa. As part of the national PNRR Tech4U project, the Villa of Casignana has been chosen as a pilot site for the development of innovative technologies for the conservation of cultural heritage, also taking into account the evolution of conservation problems related to climate change and the evolution of coastal lines. Once validated in the laboratory, these technologies will undergo field testing. Community involvement and education are emphasized for the sustainable conservation of coastal archaeological sites.

Keywords: Coastal Archaeological site; Roman villa of Casignana; Diagnostics; innovative materials for restoration

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Maria Antonietta Zicarelli, Donatella Barca, Mauro F. La Russa, Andrea Macchia, Luciana Randazzo, Michela Ricca, Silvestro A. Ruffolo, *Diagnostics and conservation of coastal archeological sites: the case study of the roman villa of Casignana, Reggio Calabria (Italy)*, pp. 660-666, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.57

Introduction

The conservation of coastal archaeological sites is a critical endeavor that aims to preserve and protect the rich cultural heritage embedded in these locations. One such site of great historical significance is the Roman Villa of Casignana, a testament to the ancient Roman civilization that once thrived along the shores.

The Roman Villa of Casignana, located in the Calabria region of southern Italy. Dating back to the 4th century AD, this coastal villa has endured centuries of natural and human-induced threats, ranging from erosion and rising sea levels to modern urbanization. Dating back to the 4th century AD, this coastal villa has endured centuries of natural and human-induced threats, ranging from erosion and rising sea levels to modern urbanization. Moreover, the site is characterized by several valuable mosaics.

Preserving such a site demands a multidisciplinary approach that encompasses archaeology, environmental science, engineering, and community engagement. The archeological site is crossed by the 106 Ionian Road and by the railway as well. Some structures of the Villa are submerged close to the seashore. In the last years the University of Calabria, through the Restoration academic course, and the Heritage Science research group, is focusing its effort on the conservation and the valorization of this site. For this reason, several research theses are carried out, they were focused on the conservation of the mosaics which suffer several degradation forms such as salt crystallization, deformation, deposits and lacks. This activity is assisted from the diagnostic analysis of the mosaic tesserae in order to gain information about the composition and the provenance of the stone materials that constituting the tesserae [1].

In addition to these activities, within the framework of the national PNNR project called Tech4U, the Villa of Casignana has been chosen as a pilot site for the development of innovative technologies for the conservation of cultural heritage, also taking into account the evolution of conservation problems related to climate change and the evolution of coastal lines. Such problem is quite critical in the case of Casignana, due to the proximity to the sea, therefore here the coastal erosion represents a significant risk.

These ongoing technologies, once validated in the laboratory, will be tested in the field. All of the above activities will be disseminated to the local community, as community involvement and education play a key role in the sustainable conservation of coastal archaeological sites. Local communities are often the stewards of these heritage sites, and their active involvement is crucial for long-term success. Educational programs, guided tours, and outreach initiatives not only raise awareness of the historical significance of the Roman Villa of Casignana, but also foster a sense of ownership and pride among the local population.

The Roman Villa at Palazzi di Casignana

The extensive complex of the Roman Villa of Casignana is located south of Calabria, 15 kilometers south of Locri, between the towns of Bianco and Bovalino, in the area known as Palazzi (Figure 1A) [2]. It experienced a period of activity from the 1st to the 4th century AD, with traces of activity persisting until the 7th century [3]. Its enduring occupation can be attributed to its privileged position.

The strategic location, chosen in accordance with Roman agronomists' principles, reflects the significant exploitation of Calabrian territories during the Roman period, recognizing their agricultural potential. In line with ancient sources, the villa stands 300 meters from the Ionian coast, facing east-west orientation (Figure 1B). Abundant water sources were likely provided by the nearby Bonamico River and possibly by an aqueduct. Moreover, the discovery of massive walls at the mouth of the Bonamico River suggests the possibility of a villa harbor, facilitating inland access via the navigable ancient river. Proximity to the main Roman road along the Ionian coast, stretching from Rhegium to Metaponto and Tarentum, was another influential factor in site selection.

Figure 1 – A) Location of Casignana in the Calabria region; B) Aerial view of the archaeological site of Casignana.

In the 4th century, the Roman Villa at Palazzi di Casignana consisted of a central courtyard, with thermal baths in the western part, service areas including latrines in the southern part, and residential area facing the sea in the eastern area. Only limited data is available for the northern area due to the presence of a modern construction [4]. Upstream from the villa, several structures were unearthed, including a monumental fountain and water collection basins/cisterns.

Internationally renowned for preserving the largest collection of Roman mosaics in Calabria, the Roman Villa of Casignana provides insight into the social status of its owner through intricate geometric and figurative compositions adorning different areas of the residence (Figure 2). Notable examples include the mosaic floors in the thermal area depicting sea nymphs riding sea monsters, geometric mosaic patterns in the caldarium of the western baths, and figurative mosaics in service areas depicting the triumph of Dionysus [5]. The complexity of the geometric and figurative motifs, along with the use of different-colored tesserae, reveals the technical skill of the mosaicists capable of fulfilling the commissions of the dominus.

Figure 2 – Some of the geometric and figural mosaics of the Roman Villa. A) Opus sectile floor; B) *Frigidarium* of the Western Baths mosaic floor; C) Polychrome geometric mosaic of *calidarium* room of Western Baths; D) Mosaic with Dionysus and Satyr; E) The Indian Triumph of Dionysus Mosaic; F) Nereid mosaic floor of frigidarium of the Eastern Baths; G) Mosaic with the Four Seasons; H) Mosaic with floral motif.

Since 2019, the University of Calabria, in collaboration with the Municipality of Casignana and relevant authorities, has actively participated in the conservation of the villa's mosaic floors. Students of the degree course in Conservation and Restoration of Cultural Heritage, at the University of Calabria, engage in practical conservation activities on-site, ensuring stabilization and various preservation operations including consolidation, cleaning and plastering of mosaic floors (Figure 3).

Figure 3 – Restoration works of the mosaics inside the Roman Villa of Casignana carried out by the students of the degree course in Conservation and Restoration of Cultural Heritage, at the University of Calabria.

The Tech4You PNR Project

The primary focus of the Tech4You ecosystem falls within the scope of the "Climate, Energy, Sustainable Mobility" area of the National Research Plan (PNR). Its main objective is to stimulate innovation potential in two of Italy's "Less Developed Regions," Basilicata and Calabria, currently classified as "Regions in Transition."

Specifically, the project aims at: building a model of sustainable economic growth that enhances the specificities of Calabria and Basilicata, making them a reference point for the revitalization of Southern Italy; promoting and strengthening collaboration between the research system, the productive system, and the territorial institutions in the Calabria and Basilicata regions; supporting processes for valorizing the results of scientific research by facilitating technology transfer, increase the dissemination of low-impact environmental technologies and improve territorial resilience [6].

The base of the project is the creation of an innovative ecosystem where scientific research conducted by universities and research centers can be transferred into commercially marketable products developed and utilized by local companies.

Tech4You stems from a project proposal presented by the University of Calabria, as the lead partner, in partnership with two other Calabrian universities, one Lucanian university, the Calabria Region, CNR, and various public and private partners. The project focuses on scientific and technological areas that focuses on the adaptation/mitigation of climate change and improvement of quality of life in different field of research.

Spokes are the operational part of the project and represent the place where the transfer of technology to the economic system is achieved.

In particular, among these, *Spoke* 4's mission is to enhance the adaptation of cultural heritage by improving the sustainability and accessibility of natural and cultural heritage (both material and immaterial) in Calabria and Basilicata. The primary goal is to mitigate the impact of climate change on particularly vulnerable sites.

The Pilot Project 4.4.1

The pilot project 4.4.1, within *Spoke* 4, aims at monitoring and mitigating the impact of climate change on cultural heritage. The actions related to the pilot project are diverse and have the general objective of preserving cultural heritage, especially those exposed to an increasing risk.

In more detail, the pilot project focuses on experimenting, validating, and prototyping sustainable and green conservation products, sensors, hybrid robots for diagnostic activities and mathematical models to verify the structural stability of culturally significant buildings over the 36-month project duration.

Among the 9 *azioni* of the pilot project, 6 of them have selected the Roman villa at Palazzi di Casignana as the real case scenario to validate the results and prototypes. Thus, there exists a synergy and an interdisciplinary approach involving various professionals such as civil engineers, environmental engineers, computer engineers, restorers, archaeologists, and microbiologists working together and sharing the same site, each with a different approach but with a shared goal of conserving the archaeological site.

Delving into further detail, the archaeological site of Casignana is the focal point of ongoing research activities aimed at diagnosis, understanding, and assessing the risks to which the site is exposed, in order to implement a series of measures aimed at least to reduce future losses in the perspective of preventive conservation. Among these measures, the development of an archaeology map of the Calabrian Ionian coast is underway, which will then be overlaid with the hydrogeological risk map to identify archaeological sites most at risk and in need of monitoring and protection.

Additionally, numerical models are being developed for the analysis of the structural stability of culturally significant buildings, aiming to determine the vulnerability of structures exposed to extreme events such as earthquakes and landslides.

Prototyping of sensors for monitoring environmental parameters, particularly developed for the coastal marine environment, is also in progress.

Furthermore, there are several research lines aimed at mitigating the degradation of cultural heritage. Among these, the experimentation of new green and sustainable products for the protection of cultural assets in the coastal marine area is being carried out. Basing on the characterization of the microbial community of the mosaics present on the site, these products exploit the ability of certain microbes to produce biomolecules known as biosurfactants capable of slowing down degradation induced by microbial growth.

Other research theme involves the experimentation of mortars supplemented with waste materials from agricultural industries with the aim to strengthen the circular economy by promoting the recovery of waste materials. Additionally, smart devices are being developed for the application of conservation products on artifact surfaces.

Another research theme focuses on creating protective barriers against saline intrusion, both on a small scale near archaeological sites, through the application of specific films, and on a large scale through the evaluation of marine intrusion into the archaeological site.

Conclusions

The preservation of the Roman Villa of Casignana, a site of immense historical and cultural significance, highlights the critical importance of multidisciplinary approaches in the conservation of coastal archaeological sites.

The recent collaborative efforts between the University of Calabria, the Municipality of Casignana have demonstrated the effectiveness of integrating archaeology, environmental science, engineering, and community engagement.

Through detailed diagnostic analyses, conservation techniques, and innovative technologies, significant strides have been made in stabilizing and preserving the mosaics, which are central to the villa's historical narrative.

Moreover, PNR Tech4You project, and in particularly *Spoke* 4 research field, has provided a robust framework for addressing the challenges posed by climate change to cultural heritage sites. The *azioni* within the pilot project have not only focused on mitigating immediate risks through advanced monitoring and prototyping sustainable conservation products but have also laid the groundwork for long-term strategies aimed at enhancing the resilience of cultural assets.

In conclusion, the ongoing research and conservation activities at the Roman Villa of Casignana exemplify a model approach for the preservation of coastal archaeological sites. The interdisciplinary collaboration, innovative technological applications, and strong community engagement represent a comprehensive strategy for confronting the multifaceted challenges of cultural heritage conservation in the face of environmental changes. As these methodologies continue to evolve, they promise to enhance the resilience and longevity of heritage sites, ensuring their preservation to the future generations.

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SESSION

MORPHOLOGY AND EVOLUTION OF COASTLINES AND SEABEDS

Chairperson: Giovanni Sarti
Department of Earth Sciences
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MORPHOLOGY AND EVOLUTION OF COASTLINES AND SEABEDS

The dynamic interplay between natural processes and human activities shapes coastal and marine landscapes, positioning them as vital zones for environmental research and management.

The *Morphology and Evolution of Coastlines and Seabeds* session aims to explore a variety of approaches and studies that reveal the complexity of these ecosystems, highlighting their fragility and resilience.

The studies cover ecological conservation, sustainable development, and the integration of advanced technologies such as machine learning, 3D GIS, and remote sensing to analyze coastal dynamics.

Case studies from Italy, Spain, and Croatia will be presented, highlighting the role of innovation in addressing climate challenges, guiding coastal defense, and informing risk management strategies for sustainable environmental management.

From the sandy beaches of Sardinia with its *"Posidonia oceanica"* banks (*Cabrita et al.*) to the innovative use of artificial reefs in Riccione (*Cleo and Santi*), the examples presented illustrate the delicate balance between ecological conservation and sustainable development.

Cutting-edge methodologies, such as the application of machine learning to soil salinization studies (*Della Vaglie and Martellozzo*) and 3D GIS techniques to analyze cliff morphodynamics (*Cohen et al.*), demonstrate how technology can improve our understanding and support informed decision-making.

Efforts to monitor coastal erosion, such as studies in Molise (*Di Paola et al.*), and modeling of sediment dispersal in Spain and Croatia (*Lopez and Pagan, Pikelij et al.*), underline the urgent need to address the challenges posed by climate change and human pressures.

Similarly, innovative tools such as unmanned aerial vehicles (*Lupicchini et al.*) are advancing research on the impacts of different parameters on coastal systems.

This session also highlights the transformative role of remote sensing and other advanced technologies in studying coastal dynamics.

Examples include the reconstruction of beach ridges in the Ombrone river delta (*Mammì and Rossi*), shoreline detection using hyperspectral imagery in the Gulf of Oristano (*Terracciano et al.),* and monitoring of soil sealing along Mediterranean coasts (*Iasillo et al.*).

These interdisciplinary studies deepen our understanding of coastal processes and provide strategies for coastal defense (*Garcia Lozano et al.*) and hazard management (*Rizzo et al.*).

FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Laura Bonora, Marcantonio Catelani, Matteo De Vincenzi, Giorgio Matteucci (edited by), *Tenth International Symposium "Monitoring of Mediterranean Coastal Areas: Problems and Measurement Techniques". Livorno (Italy) 11th-13th June 2024*, © 2024 Author(s), CC BY-NC-SA 4.0, published by Firenze University Press, ISBN 979-12-215-0556-6, DOI 10.36253/979-12-215-0556-6

By bridging scientific innovation with practical applications, this session contributes to the ongoing discourse on sustainable management of coastal and marine environments.

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ONE-YEAR EVOLUTION OF A MEDITERRANEAN SANDY BEACH WITH *POSIDONIA OCEANICA* BANQUETTES (ARBOREA, SARDINIA, ITALY)

Paulo Cabrita, Riccardo Brunetta, Juan Montes, Sabrina Terracciano, Enrico Duo, Paolo Ciavola and Clara Armaroli

Abstract: Sandy coasts represent 40 % of global shorelines and are essential for coastal protection and for their eco-biological value. Natural solutions are increasingly studied to provide beach protection while enhancing ecosystem services, such as seagrass protection and planting. This study investigates the morphological evolution of a beach characterised by a low human impact, where *Posidonia oceanica* is present and forms banquettes. Fieldwork campaigns, including topographic surveys and drone mapping, were conducted over a period of 1.5 years. During one of the campaigns a storm led to the formation of extensive Posidonia banquettes, particularly in the southern part of the beach, a trend that was observed in all surveys. This distribution influenced erosion trends, with long medium-term analysis showing overall erosion, especially in northern areas with fewer banquettes and a dune retreat of around 3 meters. These findings highlight the critical role of Posidonia banquettes in protecting the dunes from erosion, at least locally, although significant erosion over 1.5 years occurred in the whole studied area, suggesting that further investigations are needed.

Keywords: *Posidonia oceanica*; Banquettes; Beach Morphology; Coastal Storms; Geomorphological evolution.

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Paulo Cabrita, Riccardo Brunetta, Juan Montes, Sabrina Terracciano, Enrico Duo, Paolo Ciavola, Clara Armaroli, *One-Year Evolution of a Mediterranean Sandy Beach with* Posidonia oceanica *Banquettes (Arborea, Sardinia, Italy)*, pp. 671-682, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.58

Introduction

Sandy coasts represent 40 % of the world's coastline [1], making them the first line of defences from storm events. They have an important eco-biological value and are essential for the conservation of dune ecosystems. They also provide multiple services, including to the local economy [2]. The characteristics of sandy beaches can vary depending on wave exposure, tidal regime and several other factors, such as the presence of inlets, promontories and cliffs [3], which leads to different beach morphologies. A highly influential factor controlling a beach's morphological response is sediment supply. In the last century, human interventions have highly affected sediment transport due to the construction of beach protections, dams, and other infrastructures, limiting longshore transport and the supply from rivers [4]. The lack of sediment can lead to changes in beach dynamics and beach retreat in the medium term, affecting the response of the beach to short-term coastal events, such as coastal storms [4].

The beach morphology is highly susceptible to coastal storms, whose frequency and intensity vary seasonally. During the winter months, the storm influence is higher, resulting in a so-called winter beach profile, while during the summer months, the beach presents a summer beach profile [4]. The typical winter beach profile corresponds to a steeper slope and narrower beach profile, while during summer, the opposite condition occurs[5]. If a beach does not have the proper sediment supply to recover from the storm impact, which can remove sand from the beach cell, long-term erosion may occur [4].

During the last decades, several studies were carried out to identify the most efficient methods to mitigate the impact of storms on the beach without affecting beach ecosystems. In many cases, building "grey" structures to reduce erosional trends might indirectly affect the equilibrium of nearby systems. Since hard coastal defences are becoming unsuitable due to high maintenance costs and undesired ecological impacts [6], natural "green" solutions are preferred to reduce beach erosion [7], such as introducing seagrass to mitigate the wave action on the shoreface. Seagrass provides high ecological value to the area as it represents an ecosystem service (e.g. first producers, acting as a nursery and home to different species ranging from foraminifers to macrozoobenthos) [7,8]. Seagrass meadows' presence improves sediment production and trapping and can mitigate the effects of waves on the beach by attenuating the wave height and the currents associated with it, either in normal or extreme conditions [9–12]. Although some studies have investigated how the seagrass influences the beach response during an extreme event, more in-depth investigations are needed.

A typical seagrass species present in the Mediterranean Sea is the *Posidonia oceanica*, which has been studied throughout the years [7,13–23]. It has medium-height leaves between 30 cm and 40 cm and can be found in depths up to 40 m [8,19]. The *Posidonia oceanica* is also known for forming banquettes on the emerged beach [16,20,24–28]. Banquettes are produced by the deposition of dead seagrass leaves on the beach, often creating a compact and cohesive mound on the shoreface (Figure 1). These structures and the meadows of Posidonia are responsible for the mitigation of wave action and beach erosion [14,20,24,27,29]. The presence of banquettes can be important in controlling beach morphology, especially during extreme events. However, due to their visual impact on beach users and tourists, banquettes of *Posidonia oceanica* are often removed as people dislike of its presence on the beach. However, since a certain amount of sediment is trapped in the banquettes, a portion of the total sediment budget is lost out of the system [24,27,28], exacerbating the negative effects of removing a natural beach protection layer.

Figure 1 – *Posidonia oceanica* banquettes (Arborea Beach, refer to Figure 2 for the location).

An example of a beach characterised by the presence of unaltered banquettes is Arborea Beach, located in the Gulf of Oristano on the western coast of Sardinia (Italy) (Figure 2a). The Gulf of Oristano is a semi-enclosed embayment with a depth average of 15 m and a maximum depth of 25 m, with a total area of 150 km^2 characterised by salt marsh systems and lagoons located between an industrial harbour and a touristic-fishermen harbour in the northern portion. The Gulf is exposed to three different wind regimes from the northwest (Mistral, the most common), Southwest (Libeccio) and Southeast (Sirocco). The area has a microtidal regime with a maximum range of 20 cm (+/-10 cm) [30]. The Gulf of Oristano presents a high amount of Posidonia meadows, covering around 70 % of the seabed [31]. Arborea Beach, located in the southern part of the Gulf of Oristano, was selected because of the presence of banquettes of Posidonia (Figure 2b). Due to its positioning, the beach is more exposed to waves from the NW.

Human infrastructures are found on Arborea Beach, such as a road and a car park crossing the dunes, some walking paths on the dunes, and a bunker from WWII located on the beach. Nevertheless, the *Posidonia oceanica* on the beach is not influenced by human intervention (i.e. banquette removal), turning the area into a good example for understanding the natural morphological evolution. The study analyses on one and a half years beach dynamics (September 2022- April 2024) and the effects of a storm that occurred in September 2022 (Figure 3). The 2022 storm had a maximum significant offshore height value of 2.83 m, mainly from the WNW (Figure 3).

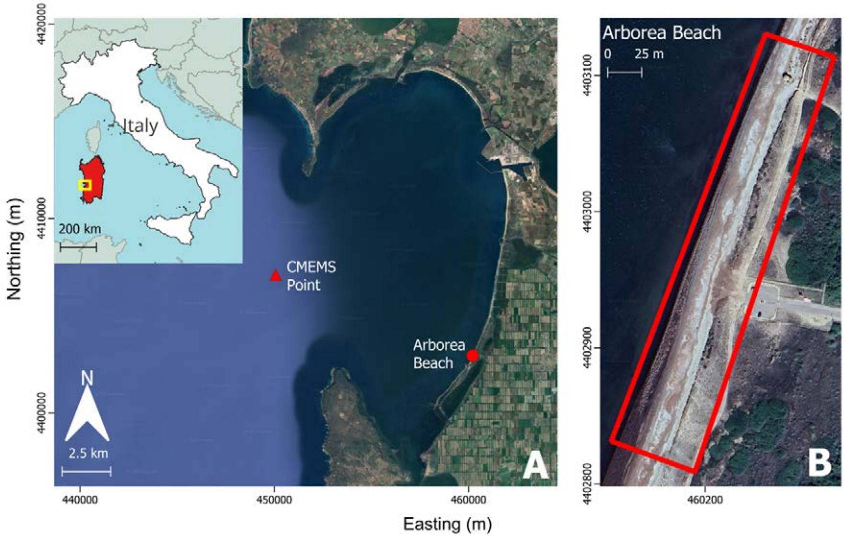

Figure 2 – a) The yellow square on the top left image represents the Gulf of Oristano. The red circle represents the location of the case study, Arborea Beach, on the Gulf of Oristano, on the west coast of Sardinia Island, Italy, while the red triangle represents the Wave data extraction point from Copernicus Marine Environment Monitoring Services (CMEMS). b) The area highlighted in red represents the surveyed area of Arborea Beach.

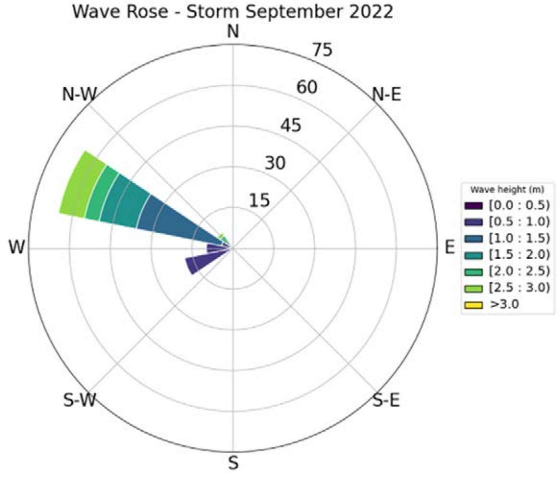

Figure 3 – Wave direction and heights offshore during the event of 2022. The wave information was extracted from the CMEMS point.

Materials and Methods

The medium- and short-term (Storm 2022) morphological evolution of Arborea Beach was investigated, focusing on profile evolution, volume changes, and the impact of Posidonia banquettes on controlling beach changes. Four surveys were undertaken over one and a half years (September 2022, May 2023, October 2023 and April 2024), where topographic data was collected using an RTK-DGPS Trimble R8 and an aerial drone (DJI Phantom Vision 3+). The RTK-DGPS was used in two contexts: (1) using the stop-and-go technique to collect the ground elevation for four cross-shore profile locations on the emerged beach (Figure 4), and (2) to collect the position of the ground control points (60 cm x 60 cm red and white squares) for the aerial drone flights. The aerial drone took multiple photos of the emerging beach, which were processed through the photogrammetric technique Structure-from-Motion (SfM) using the "Agisoft Metashape" software, creating high-resolution digital elevation models (DEMs) and orthophotos of the area of interest. The orthophotos were mainly used to identify the position and extension of *Posidonia oceanica* banquettes. The DEMs were used to calculate the difference in volume between fieldwork campaigns. The accuracy of each DEM was evaluated by estimating the root mean square error (RMSE) using the points obtained from the profiles as validation. After validation, the DEMs of Difference (DoD) were calculated using the Geomorphic Change Detection software [32]. This tool estimates vertical and volume variations between DEMs, considering the propagation of individual errors.

Knowing the related uncertainties (i.e. RMSE), it is possible to estimate a threshold for change detection (TCD) below which the variations are not considered significant. This will allow the program to detect and consider only changes higher than the threshold, improving the quality of the interpretation of the analyses. A limitation of the DoD calculation is that it can only be applied to emerged areas; therefore, the underwater changes are not detected.

Regarding the presence of *Posidonia*, the difficulty in quantifying the seagrass debris volume limits the analysis since no reference level can be used due to the vertical changes occurring on the surface under the banquettes. Therefore, the analysis of *Posidonia* was restricted to the total area where the seagrass accumulated. The identification of banquette limits was made manually using the orthophotos. The criteria used were based on the presence of *Posidonia* structures, colour and sand.

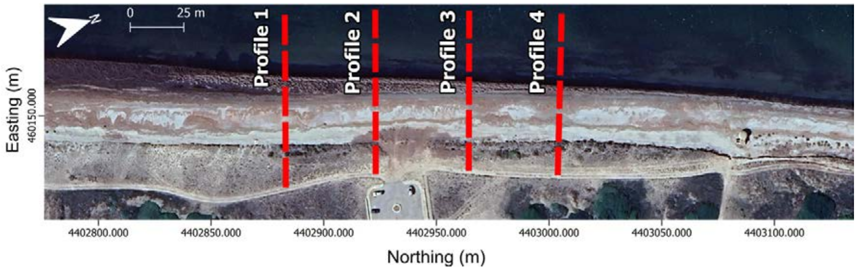

Figure 4 – The four cross-shore profiles were located using the RTK-DGPS in all the field campaigns. Geographical coordinates are in the WGS84/UTM zone 32N system (EPSG:32632).

Results

When comparing the profile data throughout the year and a half of the field surveys, large horizontal and vertical changes are detectable in all profiles (Figure 5). Assuming 0 m as the limit between subaerial and wet environments, there is a clear shoreward displacement of the water line. Regarding the vertical changes, there is a noticeable decrease in elevation along the four profiles. A vertical decrease above 1 meter can be noted in all profiles. Although a dune retreat can be detected in all profiles, the most affected ones were profiles 3 and 4; the dune retreated around 3 meters with a vertical erosion of 1 meter over the whole analysed period (Figure 5).

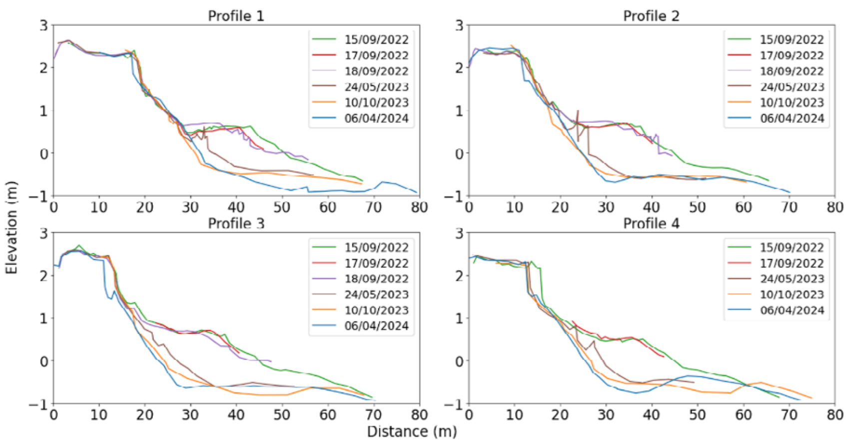

Figure 5 – Cross-shore elevation of the four profiles using the most inland point of each profile as the reference point.

In Figure 5, some "peaks" in the profiles associated with the presence of *Posidonia oceanica* banquettes can be observed. The presence of Posidonia banquettes were observed during the different fieldwork campaigns. As mentioned, a coastal storm occurred during one of the fieldwork campaigns. The storm caused the formation of *Posidonia oceanica* banquettes along the beach, which occupied an area close to 2250 m^2, while the total study area is about 1.62x104 m^2 (Figure 6). The banquette thickness and extension decreased northward; a tendency observed during the fieldwork campaigns after September 2022.

Although the *Posidonia oceanica* banquettes were formed on the foreshore after the storm, the foreshore area of Arborea shows a general decrease in elevation where the *Posidonia oceanica* banquettes were formed, while the berm elevation increased (Figure 7a). Also, during this event, the dune was not affected. It is not possible to quantify the amount of erosion and accretion of sediment volumes for the whole study area correctly due to the lack of information on the volume of the banquette.

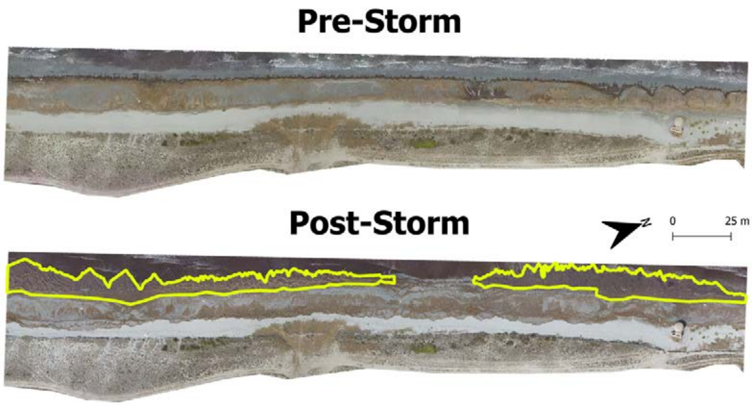

Figure 6 – Pre- and Post-Storm orthophotos. The Posidonia banquettes are highlighted in yellow. In the pre-storm picture on the top, there were no Posidonia banquettes on the beach.

This limitation did not affect the medium-term evolution analysis, where the DEMs did not show Posidonia banquettes on the beach (Figure 7b). Regarding the medium-term analysis, the beach shows a major erosion in the common part between the DEM from 2022 and 2024, reaching a sediment loss of about 1500 m^3 (Table 1). An hotspot of erosion is focused mainly on the dune on the northern part of the beach, which is the major contributor to the erosion values. The accretion values are very limited compared to erosion, with a value of about 10 m^3 (Table 1).

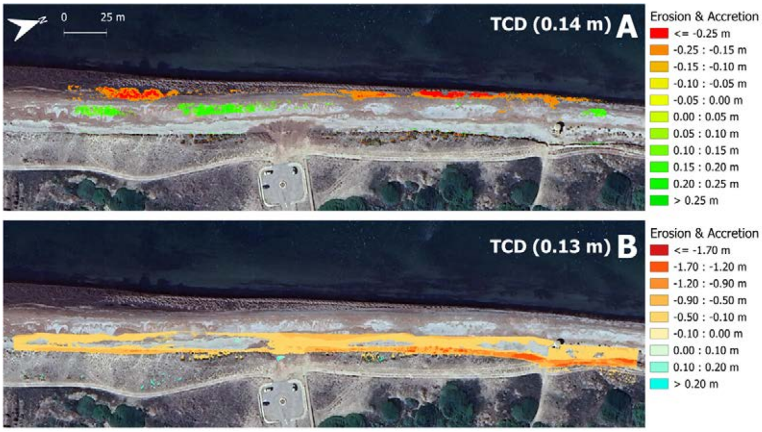

Figure 7 – DEMs of Difference where the beach is analysed according to a reference DEM. a) The Storm's DEMs of Difference, being the DEM of reference the one of 15/09/2022 and final DEM the one of 18/09/2022, pre and post-storm, respectively. b) the DEMs of Difference for the whole period of the fieldwork campaigns (medium-term), being the DEM of reference the one of 15/09/2022 and the final DEM the one of 06/04/2024.

Table 1 – The table shows the volume of accretion and erosion related to the DEMs of Difference of the Storm event (15th to 18th of September 2022) and medium-term evolution (15/09/2022 to 06/04/2024).

	Storm (TCD 0.14m)	Medium-term (TCD 0.13 m)
Accretion (m^3)	66.1	10.2
Erosion (m^3)	164.0	1571.4
Total (m^3)	-97.8	-1561.4
Error ($\pm m^3$)	119.1	431.0

Discussion

The results of this study regarding the morphological evolution of Arborea Beach are divided into two periods: short-term and medium-term. The short-term event did not affect the dune of the Arborea beach; however, important changes occurred on the beach, such as the deposition and formation of the *Posidonia oceanic* banquettes. The evolution of a banquette due to a coastal storm, from 0 m^2 to around 2250 m^2 (Figure 6) is in agreement with the literature regarding the combination of wave action, suspended *Posidonia* and banquette formation [26]. Although the dune did not suffer any erosion during the analysed storm event, other parts of the beach showed changes. The presence of *Posidonia* banquettes on the coast increased the beach height, behaving as small "cliffs" of organic matter (Figure 1 and profile 1,2,3 in Figure 5); however, even with the newly formed banquette, the beach face area witnessed surface lowering, as evidenced in figure 7a. This suggests a strong erosion on the beach face because the surface level of the banquette on 18/09/2022 was even lower than the pre-storm (15/09/2022) elevation. This observation is supported by Figure 5, where the post-storm (18/09/2022) beach profiles showed up to 40 cm of lower elevations compared to pre-storm (15/09/2022). In this case, it is not possible to know the volume of sediment eroded since there is a layer of *Posidonia oceanica* above the sand, and no reference layer was used. The accretion after the storm event represented 40% of the sediment loss (Table 1), though this value might be lower due to the inability to detect the changes underwater. Figure 7b shows that accretion is localised in the berm zone. Although it is not possible to quantify the percentage of sediment, part of the eroded sediment from the foreshore was likely moved to the berm.

The results presented in this study regarding the medium-term morphological evolution demonstrated an overall erosional trend. The northern part of the investigated beach is the hotspot of erosion; the dune retreated almost 3 meters between September 2022 and April 2024 (Figure 5). Although the storm of September 2022 did not affect the dune, it cannot be stated that the storms are not responsible for the erosion as they can cause the collision or overwash regimes [33]. However, a factor that can affect the discrepancy in dune erosion between the northern and southern parts of the studied beach is the recurring presence of *Posidonia oceanica* banquettes on the southern part of the beach compared to the northern portion. As mentioned, the analysis shows a larger number of *Posidonia* *oceanica* banquettes in the southern portion; the authors have also witnessed a higher presence of banquettes in the southern part of Arborea during all fieldwork campaigns. The banquettes' presence might have protected the dune from erosion as the banquettes could mitigate the effect of waves on the coast [34]. Although their formation may also be due to wave action during storm events and the presence of suspended dead *Posidonia* [26], once they remain on the coast, the *Posidonia oceanica* banquettes can behave as a first layer of protection for the dune, limiting swash elevation [34]. The lower distribution and thickness of the beach banquettes on the northern part makes the beach more exposed to wave action than the southern portion, thus leading to a higher erosion rate.

An erosive trend is ongoing along the beach; however, identifying the factors that may contribute to this evolution is not straightforward. Since Arborea beach presents a highly limited human influence (i.e. no removal of banquettes), which affects the sediment budget or surface lowering due to the operations (i.e. presence of machines on the beach) [24,25,27], the erosional trend might be caused by other factors. One important factor is the lack of sediment supply; one of the main direct sediment source might be the Tirso River on the Gulf's northern side. However, its mouth is located between structures, which can limit longshore transport, a common problem for several beaches worldwide [4]. Furthermore, the beach is situated in a gulf, which can limit sediment supply and favour erosion. Since this study is focused on a portion of the beach, it would be necessary to extend the analysis to other portions of the Gulf of Oristano, as the eroded sediment was probably transported outside the investigated area, including the submerged beach, also focusing on current and wave patterns and shoreline retreat over more extended periods.

Although it is possible to understand the erosional trend and the influence of banquettes on the beach, the analysis of the impact of additional and different storms could provide better indications on the morphodynamic behaviour of the beach, that should also include the analysis of submerged profiles.

Conclusion

This study used cross-shore profiles and aerial drone flights to discuss the short-term (i.e. storm event) and medium-term (September 2022-April 2024) morphological evolution of a beach on the West coast of Sardinia Island, where *Posidonia oceanica* banquettes are a common deposit that characterises this system. The beach showed an erosional trend, with a horizontal retreat of the shoreline and dune erosion along the beach. The results highlighted different behaviours between the study northern and southern parts, where the dunes are subjected to higher erosion on the northern section while the southern part showed an increase of *Posidonia* banquettes that became denser protecting the dune system. The changes in erosion and the banquette deposition might be related, as the deposition of *Posidonia* may reduce the effect of the waves and, therefore, protect the southern portion of the beach. According to the literature, wave action is the main factor responsible for Posidonia deposition. This coincides with the data collected from the fieldwork, especially during September 2022, when a coastal storm affected the area, which favoured the deposition of *Posidonia* on the beach. However, a lower elevation of the area was observed while the banquettes were on the beach.

The possible lack of sediment supply and the effects of the change in thickness of the banquettes may be the main factor controlling its evolution, at least in the short term. However, more analyses that cover a larger spatial-temporal interval integrated with hydrodynamic processes must be addressed to better understand the overall trend.

Acknowledgements

This work is a contribution to the OVERSEE Project, financed by ASI under contract 2022-14-U.0. We also acknowledge the support of the staff of the CNR-IAS institute for providing access to local GPS corrections and logistical support. Grants of the University of Ferrara within the EMAS PhD programme financed P. Cabrita and S. Terracciano. Juan Montes holds a Margarita Salas postdoctoral fellowship at the University of Cadiz from the Requalification of Spanish University System 2023–2024, funded by the European Union-NextGenerationEU. We want to thank Antonis Chatzipvalis and Stefano Fabbri for their support in the field campaigns.

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RICCIONE'S STUDY CASE: EXPERIMENTATION OF INNOVATIVE ARTIFICIAL REEF FOR COASTAL DEFENSE AND INCREASE MARINE BIODIVERSITY

Daniela Cleo, Renato Santi

Abstract: Riccione is a town (near Rimini) on Romagna coast, with a small harbour and with the problem of coastal erosion that, reducing the width of the beaches, can create great problems for tourist activities and buildings in case of adverse weather events (so frequent today). Since eighties of the 20th century, underwater artificial barriers have been placed on the natural sandy seabed of this area, for coastal defense from waves and storms. Initially they were only "sandbags" - bags of synthetic material filled with sand - arranged parallel to the coast, about 200 meters from the shore, at a depth of about 2/3 meters. In the last ten years, other experiments were done, with positioning of other types of submerged structures (innovative barriers as "Reef balls" and "Wmesh") always parallel to the coastline and close to shore. Monitoring results have shown the positive impact of underwater artificial barriers on water quality and increase marine biodiversity (rocky and sandy seabed) in this marine area. Several species of rocky environment colonized these reefs, increasing natural environmental richness. The experimentation is still ongoing.

Keywords: Monitoring of coastal ecosystems, Biodiversity, Underwater reefs

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Daniela Cleo, Renato Santi, *Riccione's study case: experimentation of innovative artificial reef for coastal defense and increase marine biodiversity*, pp. 683-694, DOI: 10.36253/979-12-215-0556-6.59

Introduction

Riccione is an important tourist site on Romagna coast, in Nord Adriatic Sea, Center Mediterranean, with the problem of coastal erosion highlighted since the early 20th century.

Emilia-Romagna coast is characterized by natural sandy seabed (excluding some rocky points like the promontory of San Bartolo near Cattolica – RN) with shallow waters.

Coastal erosion has reduced, over time, width and height of the beach, becoming an important problem for both tourist activities and buildings in the event of adverse weather (increasingly frequent).

The end of the 1970s saw a worsening of the problem, with consequent political intervention: with the Regional Law n.7/1979, Emilia Romagna Region promoted the realization of a project plan for the defense of the coast.

The following "Costa Plan 1981" identified the main causes of beach erosion in reduction of solid river transport to the sea, in subsidence and in construction works at sea (SLEM – Arpae – 2020).

Since the 1980s, various types of action have been taken to try to combat coastal erosion: blocking of the extraction of aggregates from the beds of watercourses of regional competence, limiting ground water abstraction to reduce human subsidence, construction of major infrastructure hydraulic, coastal direct protection and nourishment.

These last solutions, tested by the public administration, are "periodic beach nourishments" and the positioning of "artificial reefs" on the natural sandy bottom.

In Riccione it was opted for sandbags (initially and today) and concrete underwater barriers (still in the process of experimentation).

Figures 1a,b – Riccione's sandy beaches and the area with artificial underwater reefs.

The aim of our research was twofold:

1- to check if these artificial concrete underwater structures were structurally suitable for positioning on Riccione's sandy seabed (static technical testing)
2- to monitor the evolution of marine ecosystem over time, to verify the possibility to use these underwater reefs for environmental restoration.

Meteo-marine conditions, seabed and water

For the morphological and sedimentological evolution of low and sandy beaches, in the medium and long term, wave motion and the contribution of aggregates from rivers are particularly important.

One of the key factors contributing to coastal erosion is the average wave conditions, annual and/or seasonal: the regime of currents along the shore and the consequent sediment transport are important elements to consider for correct sizing of the interventions along the coast, as well as the sea level trend.

The wave motion today is monitored by the wave-measuring buoy installed off Cesenatico (FC): it measures height, direction, mean and peak period of the wave and water temperature.

These data are transmitted to the central database of the weather monitoring network managed by the Hydro-Weather-Climate Structure (Arpae - SIMC).

The tidal level is monitored by the tide gauge in Porto Garibaldi (FE).

Arpae has produced periodic studies (available on the web site) on the state of Emilia-Romagna coastline, with reference to erosion and defence interventions and with specific detail of the characteristics of the different coastal areas.

Specifically (SLEM – Arpae – 2020) Riccione's coast is characterized by:

- natural sources of sediment, that feed this area, come from the Marche coast and the river Conca;
- reduced contribution from river and close coastal areas;
- solid transport along the coast is mainly directed from south to north;
- the beaches to the south, no longer sufficiently supplied, have gone into erosion, those more north are in equilibrium or in progress thanks to the action of the Rimini pier that hinders coastal sediment transport from the south.

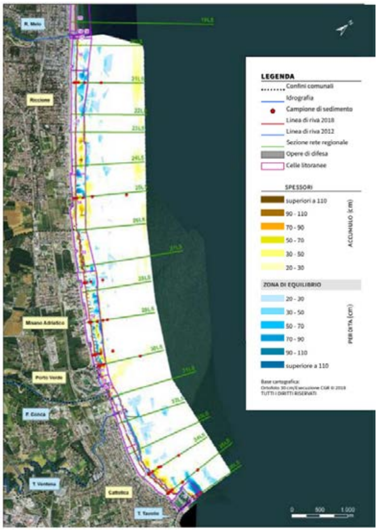
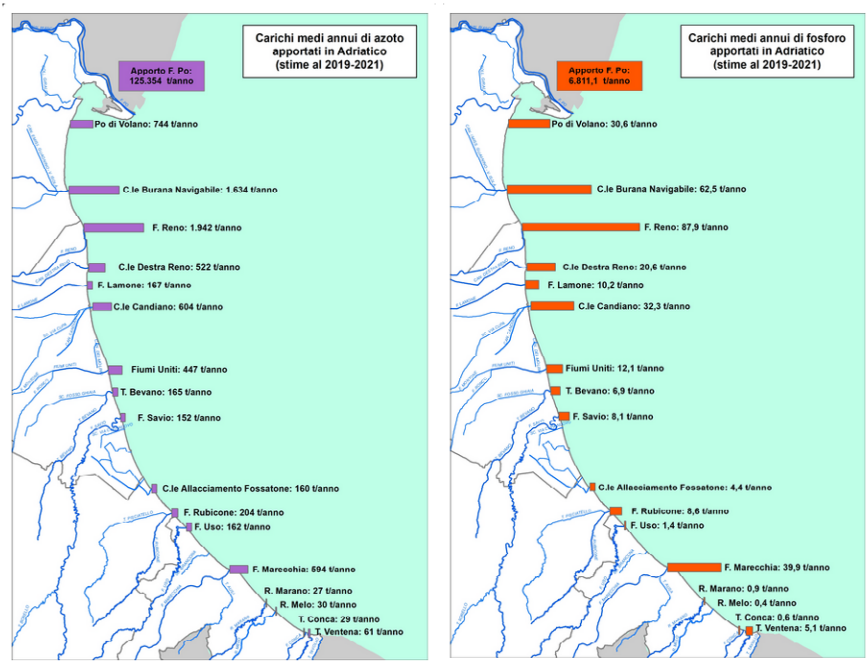


Figure 2 – Cattolica - Riccione's harbour: Accumulation and Sediment Loss Chart 2012-2018 (SLEM-Arpae-2020).

Another key factor in relation to erosion is the river inputs.

Emilia-Romagna coast receives fresh water directly from the hydrographic Padano basin and coastal basins: with reference to contrast to coastal erosion, these rivers play an important role, thanks to the aggregates that carry, which contributes, in a natural way, to the balance of the beaches.

The waters of these rivers are particularly important also because they are very rich in nutrients (especially nitrogen and phosphorus): this makes the marine waters of this stretch of coast particularly sensitive to eutrophication and very rich in fish; Nord Adriatic Sea, by quantity of fish caught, is the most productive basin in the Mediterranean [Osservatorio Socio Economico della Pesca e dell'Acquacoltura. Veneto Agricoltura, 2013].



Figures 3a,b – Average annual loads of nitrogen and phosphorus in the Adriatic Sea (Arpae, Regione Emilia-Romagna, 2018).

The influence and effect of the input conveyed by the river Po on the coastal area, are also highlighted considering the salinity value that is considerably lower along the coastal strip compared to the open sea; in addition, the large mass of fresh water introduced by the river Po (1500 m^3/s as long-term annual average: 1917-2017), represents the engine and the element characterizing the north-western Adriatic basin, able to determine and influence most of the trophic and dystrophial processes in the coastal ecosystem [Regione Emilia-Romagna - Arpae].

Types of human interventions to counter erosion

Periodic beach nourishments are made, since 1983, to nourish and to reprofile the coast and to expand the beaches, bringing sediment, initially, from quarries, from construction works, from construction of docks, from coastal accumulation zones (beaches in progress and inlets of canals and rivers) and, since 2002, from off-shore deposits.

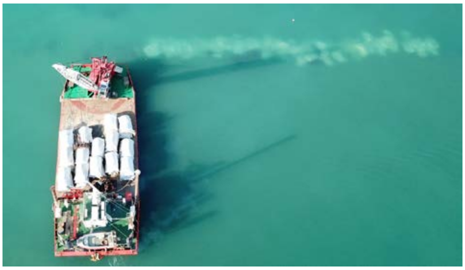
About artificial barriers, on the coast of Riccione it was chosen to experiment with systems of "underwater" reefs, contrary to what has been experienced in neighbouring territories, characterized by "emerged" barriers.

These last, are made of stone blocks, which are never, in normal marine weather conditions, below water surface. They are a unique structure, not permeable to water. They, parallel or perpendicular to the coastline, have shown problems in terms of water quality (exchange and oxygenation), beach protection and visual impact (because always visible from the shore).

On the contrary, underwater barriers are permeable to water and, allowing its passage, avoid, or strongly limit, anoxic zones.

The types of underwater reefs tested in Riccione are “sand-bags”, “Reef ball” and “Wmesh”.

Initially, in the eighties, they were “sand-bags”: bags of synthetic material, filled with sand, were positioned parallel to the coast, about 200 meters from the shore, at a depth of about 2÷3 meters, from Riccione (RN) to the border with Misano (RN), for a length of about 3 km, to reduce the strenght of the waves and combating coastal erosion. These reefs are periodically checked to restore the damaged sections by boats or storms.



Figures 4 a, b – Positioning of sand-bags.

Monitoring to verify the state of this underwater barrier, in the early 2000s, after 2004, showed an important environmental enrichment and prompted further experiments. So, in 2016, “Reef ball” were positioned: they are perforated bells in biocement. Two barriers were placed, one closer to shore and the other further offshore, each formed by five bells.

At the end of the monitoring period, the trial is not continued for several reasons (technical, structural and economic).

Figures 5 a, b – Positioning of Reef ball.

In 2017, a first small "Wmesh" test facility was placed on the seabed, about 500 m from shore, to verify its stability at sea and any critical issues.

After overcoming some technical problems and successfully monitoring the settling period, in 2020 a longer section (100 meters) was placed, about 350 m from the shore.

Wmesh are a permeable structure formed by prefabricated reinforced concrete modules; their deflector elements are able to divert the currents upwards, contributing to the breaking down and weakening of the waves.

Testing and verification of the ability of Wmesh to counter erosion is ongoing, while their positive contribution to increasing marine biodiversity is demonstrated.

Figure 6a, b, c, d – Wmesh and their positioning.

Materials and Methods

Two types of monitoring were (and are) carried out, through periodic dives, surface and underwater observations, measurements and data collection.

Technical Monitoring

The first type was structural in order to verify the stability of the structure and behavior over time, considering the sandy seabeds of Riccione.

1- Monitoring of barrier in sandbags Protocol:

The frequency is about once a month, in summer, and once every three/four months, in winter (it is strongly linked to visibility and marine weather conditions).

The control is done both from the surface and from the water, with GPS location for sites with broken bags or points where the barrier is missing/suspended.

A visual monitoring is also provided, after storms, to be done on shore, looking for any sacks broken.

In all cases, photographs are taken and GPS position is recorded.

2- Monitoring of Reef Ball:

The objective of monitoring was to verify the stability of the bells and their planimetric and altimetric displacement.

The planimetric detection was monitored by GPS tracking of the bells coordinates, with a reference to shore,

The altimetric detection was measured with a metric bar, measuring the distance from the top of each bell to the surface and the length of the part outside the sand.

In each monitoring were detected also the time of data collection and the value of the tide of the day, to standardize measurements.

The frequency was after 20 days in the first month of placement and after three months thereafter (it is strongly linked to visibility and marine weather conditions).

The monitoring lasted about one year.

3- Monitoring of Wmesh:

The objective of monitoring was to verify the stability of Wmesh and its planimetric and altimetric displacement.

Monitoring was done as for Reef Ball.

The monitoring lasted about two years for each product.

Biological Monitoring

The second is a biological monitoring, to check the status of local biodiversity:

1- *Visual census and photographic documentation Protocol*:

An underwater survey was regularly carried out, at the same points of the reefs, to check state and evolution of biodiversity and photographs were taken to list the organisms present. This type of monitoring is still in place.

The periodicity is monthly in the summer months, every 3/4 months the rest of the year and, anyway, dependent on visibility and marine weather conditions.

2- Reef check Italy for "GBA" – Great Barrier Adriatic Protocol:

This monitoring was conducted from 2016 to 2022 (except the stop activity for COVID-19) with data transmission to UNIBO for analysis of results.

Teams of two operators, with a monthly frequency (however bound to the visibility in water and marine weather conditions) have carried out a monitoring:

a) photograph, taking photographs on areas, chosen at random, and circumscribed by a rectangular frame. Photographs then sent to UNIBO for computer analysis.
b) with square: the operators recorded the presence/absence of ten target species, using a 50x50 cm PVC square, divided into 25 sub-squares, randomly placed on the barrier, vertically, as per GBA protocol. These target species have specific biological and ecological characteristics which are suitable for monitoring possible ongoing changes. The aim is to better understand the ecological role played by each species in the northern Adriatic range.
c) All measurements recorded include depth, temperature and geographic coordinates.
d) Both monitorings were done observing a distance from the seabed of at least 25 cm to avoid inconsistencies given by anoxic zones.


Figures 7a,b – Monitoring activities

Studies on environment and biodiversity have also been (and are being) carried out in collaboration with various research institutes. Each study involves sampling and monitoring with specific protocols established by the client.

Results

Results of technical monitoring

As regards technical monitoring, Reef Ball and Wmesh behaved differently. About Reef Ball, they failed initial static tests due to important sinking problems.

A second experiment was carried out, in 2017, placing them on top of a sheet and closer together to avoid tipping over and sinking. The static and stability problems found have not been completely resolved, so the trial has ended.

About Wmesh, measurements made showed an initial sinking of about 70 cm of all structures, followed by their stabilization.

Over time, this type of underwater barrier has proved to be stable and resistant to the impact of waves even during major tidal waves.

The horizontal wings, although concreted by the benthos, have always allowed the passage of water, maintaining the benefits of permeable barriers.

The Wmesh experiment on erosion contrast is still ongoing.

Results of biological monitoring

Periodic monitoring of these submerged barriers, starting from the 2000s, has demonstrated an unexpected great environmental enrichment: the insertion, in a stretch of sea very rich in nutrients, on a sandy seabed, of hard artefacts attracted marine organisms typical of rocky seabed.

Monitoring, visual observation and data and photography collection, carried out over the years, have shown that:

- the underwater reefs were quickly (already in the first month since positioning, in the late spring and summer months) colonized by sessile organisms
- the hard substrate and the nutrient richness of water have allowed the creation of a new ecosystem, non-existent before the positioning of the barriers.
- colonization by new sessile species has led to further enrichment of biodiversity, attracting fin fish.
- bioconstructing organisms (as Sabellaria spp, sedentary tube-dwelling marine polychaetes) have contribuited to strengthening these anthropic structures, giving a further boost to the colonization of plants, algae and animals.
- overall, these submerged structures have resulted in an increase marine biodiversity and improvement of environmental characteristics and sea water parameters (water oxygenation in the sea tract towards land) relative to an emerged barrier. Below some examples of the different phyla identified in the investigated area.


Figures 8 a, b – Artificial reefs and the underwater colonization.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Figures 9, 10 – Phylum Cnidaria – Class Anthozoa.
Figure 11, 12 – Phylum Mollusca – Class Gastropoda.


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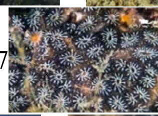
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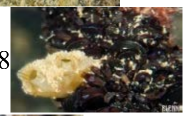
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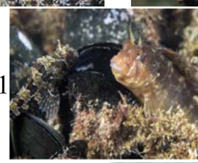
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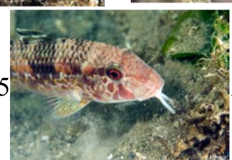
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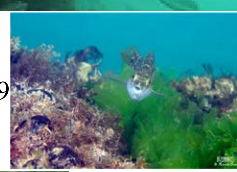
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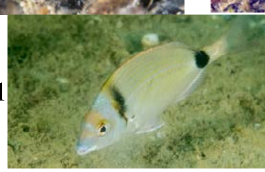
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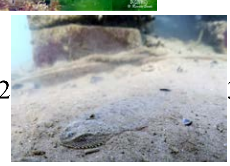
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Figures 13,14,15 – Phylum Arthropoda – Class Crustacea.
Figures 16,17 – Phylum Arthropoda – Class Crustacea.
Figures 18,19 – Phylum Chordata – Class Ascidiacea.
Figures 20 – Phyla Cnidaria – Class Scyphozoa and Arthropoda – Class Crustacea.
Figures 21 – Phylum Mollusca – Class Gastropoda.
Figures 22 and subsequent – Phylum Chordata – Class Actinopterygii.

Underwater monitoring has demonstrated, to date, the presence, in the area of underwater reefs, of the following seabed organisms plus algae and fin fishes.

The list (figure 34) is to be considered indicative and not exhaustive; the last column shows the environment of each organism to further highlighting the increase in biodiversity caused by the positioning of these underwater barriers.

Phylum	Class	Family	Species	Seabed's type
Porifera	Demospongiae	Clionaidae	*Cliona adriatica*	Rocky
Porifera	Demospongiae	Chondrillidae	*Chondrilla nucula*	Rocky
Phoronidae	-	Phoronidae	*P. hippocrepia*	Rocky
Bryozoa	-	-	*Different species*	Rocky
Anellida	-	Sipunculidae	*Sipunculus nudus*	Sandy
Echinodermata	Asteroidea	Astropectinidae	*Different species*	Sandy
Echinodermata	Ophiuroidea	Ophiuridae	*Ophiura ophiura*	Sandy
Echinodermata	Echinoidea	Loveniidae	*E. cordatum*	Sandy
Arthropoda	Malacostraca	Squillidae	*Squilla mantis*	Sandy
Arthropoda	Malacostraca	Palaemonidae	*Different species*	Rocky
Arthropoda	Malacostraca	Paguridae	*Different species*	Rocky
Arthropoda	Malacostraca	Diogenidae	*Different species*	Sandy
Arthropoda	Malacostraca	Eriphiidae	*Eriphia verrucosa*	Rocky
Arthropoda	Malacostraca	Carcinidae	*Carcinus aestuarii*	Rocky
Arthropoda	Malacostraca	Carcinidae	*L. vernalis*	Sandy
Arthropoda	Malacostraca	Mysidae	*Leptomysis sp*	Sandy
Arthropoda	Malacostrata	Caprellidae	*Caprella sp*	Rocky
Cnidaria	Exacorallia	Actiniidae	*Actinia cari*	Rocky
Cnidaria	Exacorallia	Actiniidae	*Anemonia viridis*	Rocky
Cnidaria	Exacorallia	Hormathiidae	*C. parasitica*	Sandy
Cnidaria	Hydrozoa	Eudendriidae	*E. racemosum*	Rocky
Cnidaria	Hydrozoa	Eudendriidae	*E. glomeratum*	Rocky
Cnidaria	Hydrozoa	Campanulariidae	*Obelia dichotoma*	Rocky
Cnidaria	Hydrozoa	Aglaopheniidae	*A. kirchenpaueri*	Rocky
Cnidaria	Hydrozoa	Sertularellidae	*Sertularella ellisii*	Rocky
Anellida	Polychaeta	Arenicolidae	*Arenicola marina*	Sandy
Anellida	Polychaeta	Serpulidae	*Hydroides sp*	Rocky
Anellida	Polychaeta	Serpulidae	*P. triqueter*	Rocky
Anellida	Polychaeta	Sabellariidae	*S. spinulosa*	Rocky
Mollusca	Gastropoda	Trochidae	*Gibbula sp*	Rocky
Mollusca	Gastropoda	Trochidae	*Phorcus mutabilils*	Rocky
Mollusca	Gastropoda	Cerithiidae	*C. alucaster*	Sandy
Mollusca	Gastropoda	Turritellidae	*T. communis*	Sandy
Mollusca	Gastropoda	Aporrhaidae	*A. pespelecani*	Sandy
Mollusca	Gastropoda	Naticidae	*N. millepunctata*	Sandy
Mollusca	Gastropoda	Naticidae	*Neverita josephinia*	Sandy
Mollusca	Gastropoda	Epitoniidae	*E. clathratulum*	Sandy
Mollusca	Gastropoda	Muricidae	*Bolinus brandaris*	Sandy
Mollusca	Gastropoda	Muricidae	*Hexaplex trunculus*	Sandy
Mollusca	Gastropoda	Muricidae	*Rapana venosa*	S/R
Mollusca	Gastropoda	Muricidae	*O. erinaceus*	Rocky
Mollusca	Gastropoda	Nassaridae	*N. mutabilis*	Sandy
Mollusca	Gastropoda	Nassaridae	*N. nitidus*	Sandy
Mollusca	Gastropoda	Nassaridae	*Cyclope neritea*	Sandy
Mollusca	Gastropoda	Nassaridae	*Acteon tornatilis*	Sandy
Mollusca	Gastropda	Tethydidae	*Tethys fimbria*	Sandy
Mollusca	Bivalvia	Arcidae	*Arca noae*	Rocky
Mollusca	Bivalvia	Arcidae	*A. inaequivalvis*	Sandy
Mollusca	Bivalvia	Arcidae	*Anadara transversa*	Sandy
Mollusca	Bivalvia	Mytilidae	*M.galloprovincialis*	Rocky
Mollusca	Bivalvia	Pectinidae	*A. opercularis*	Sandy
Mollusca	Bivalvia	Pectinidae	*F. glaber glaber*	Sandy
Mollusca	Bivalvia	Pectinidae	*F. glaber proteus*	Sandy
Mollusca	Bivalvia	Pectinidae	*Mimachlamys varia*	Sandy
Mollusca	Bivalvia	Anomiidae	*Anomia ephippium*	Rocky
Mollusca	Bivalvia	Ostreidae	*Ostrea edulis*	Rocky
Mollusca	Bivalvia	Ostreidae	*Ostrea stentina*	Rocky
Mollusca	Bivalvia	Ostreidae	*Crassostrea gigas*	Rocky
Mollusca	Bivalvia	Cardiidae	*A. tubercolata*	Sandy
Mollusca	Bivalvia	Mactridae	*Mactra stultorum*	Sandy
Mollusca	Bivalvia	Mactridae	*Mactra corallina*	Sandy
Mollusca	Bivalvia	Mactridae	*Spisula subtruncata*	Sandy
Mollusca	Bivalvia	Solenoidea	*Solen marginatus*	Sandy
Mollusca	Bivalvia	Solenoidea	*Ensis minor*	Sandy
Mollusca	Bivalvia	Tellinidae	*Different species*	Sandy
Mollusca	Bivalvia	Veneridae	*Chamelea gallina*	Sandy
Mollusca	Bivalvia	Veneridae	*R. decussatus*	Sandy
Mollusca	Bivalvia	Veneridae	*R. philippinarum*	Sandy
Mollusca	Bivalvia	Corbulidae	*L. mediterraneum*	Sandy
Mollusca	Scaphopoda	-	*Different species*	Sandy
Mollusca	Cephalopoda	Sepiidae	*Sepia officinalis*	Sandy
Chordata	Ascidiacea	Ascidiidae	*P. mammillata*	Sandy
Chordata	Ascidiacea	Styelidae	*Botryllus schlosseri*	Rocky

Figure 34 – List of species censed.

Discussion

The experimentation on these innovative underwater barriers' capacity to contrast coastal erosion is still ongoing.

Underwater monitoring activities, focusing on environment, have shown a constant enrichment of biodiversity in the underwater reefs area and the data collected also seem to show the state of health of current community.

A study was recently published regarding A. viridis microbiota and its ability to adapt and respond to summer stressor factors, which anthropic impact and environmental and anthropogenic conditions: "Plasticity of the *Anemonia viridis* microbiota in response to different levels of combined anthropogenic and environmental stresses"; Palladino et al.; 2022.

Two touristic Center Mediterranean coastal locations were compared, Riccione (Italy) and Cap de Creus (Spain).

From this research it would appear that the anemones' microbiota, coming from Riccione's underwater reefs, is able to respond to changes in environmental conditions and combined stresses of anthropogenic and environmental origin, while keeping a close connection with the surrounding environment through selection of potentially symbiont partners [Palladino et al., 2022].

In light of the data collected and the studies done, these innovative underwater reefs could be employed also for ecosystem restoration, increasing biodiversity and possible detoxifyng activity by the microbiota. Studies are underway.

A question about research is the limited area covered by Wmesh.

The sandbags' reef has a length of about 3km and, on its whole length, it has been found colonization and environmental enrichment, with continuity of data on the species censuses.

It would be interesting to have a lengthening of the Wmesh in order to verify whether, what has been observed at the level of biodiversity in these years, can be repeated in the same way or if the development can be different.

Conclusion

The experimentation of different types of underwater barriers to mitigate the force of waves and counteract erosion in the coastal area of Riccione (RN) is still underway and, today, is centered on "sand bags" and "Wmesh".

The inclusion of hard artefacts on a sandy seabed, in Nord Adriatic Sea (very rich in nutrients) has allowed an increase in marine biodiversity to the benefit of environmental richness, water parameters, tourism and education and protection of marine environment.

Acknowledgements

We would like to thank all the collaborators of Blennius Riccione Association who, over the years, have participated and are participating, directly and indirectly, in support activities, monitoring, measurements and data collection.

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IDENTIFYING CLIFFS MORPHODYNAMICS: A 3D GIS APPROACH FOR A BETTER HAZARD MANAGEMENT. EXAMPLES IN CROATIA

Olivier Cohen, Kristina Pikelj, Emmanuel Blaise

Abstract: In this paper, we present a simple method for elaborating and mapping a multivariate index for coastal cliffs. The final map aims to classify zones of low, medium and high hazards related to morphodynamics. This classification is a synthetic description that must later be explained with geological and other features.
The index is calculated on regularly and closely spaced transects along the coastline. It uses three easily determined parameters: the evolution of the cliff edge, the height and the mean slope.
The sites selected for this study are located in Croatia. The first coastal cliff is located on the island of Vrgada. Massive episodic rockfalls usually occur on this 90° steep cliff. The second is the coastal cliff of Duilovo in the urban area of Split. Erosion processes along this cliff include rockfalls and landslides supported by water, while weathered sediment are moved downslope by gravity during dry periods. At both sites wave action is not the key process in the formation in cliff formation, but it carries away debris and other forms of material that have accumulated downslope. The morphodynamics analysis on both sites was tested and is presented for the first time.

Keywords: Cliffs, hazards, Geographical Information System, Croatia

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Introduction

About 52 % of the world's coastlines consist of cliffs [27]. Surprisingly, these cliffs are less studied and less known in the scientific community than low-lying sedimentary coastlines [18]. However, these coastlines can be highly vulnerable, especially when human infrastructures are built close to eroding areas [4, 21, 24, 26].

Some scientific studies focus on mapping coastal evolution to quantify and predict shoreline retreat, e.g. through a diachronic analysis of the cliffs digitized on historical maps and aerial photographs [9, 13]. Many researches aim to identify the geological, marine and meteorological factors involved in the cliff morphology and slope processes at short time scale [10, 15,16, 21]. Quantitative analysis of cliff morphodynamics is less frequently studied [22], perhaps because it is difficult to conduct field measurements in an environment with a steeper and more restrictive topography than that of a beach or dune.

However, in the last 25 years, airborne LIDAR and more recently digital photogrammetry have seen increasing success in the scientific community of geoscientists [6, 13]. These techniques help in the acquisition of a large amount of precise data as well as in the transition from 2D to 3D mapping and terrain modelling. Such successive topographic surveys are very valuable for assessing the morphodynamics of cliffs, for example, by revealing not only changes in the horizontal displacement of the coastline, but also the profile characteristics and volume of the cliffs and their evolution [11].

In this paper, we present a simple method for developing and mapping a multivariate coastal cliff hazard index. The method uses two data sets that are quite easy to obtain nowadays: (1) 2D data: the shoreline evolution, for example by a diachronic analysis of aerial photographs; (2) 3D topography data extracted from digital models (DM) calculated from digital photogrammetric processing and their derivatives: cliff height and slope. Measurements are then taken at regularly and closely spaced transects along the coast. The multivariate synthesis is calculated using cluster analysis. The final map aims to classify low, medium and high hazard zones in terms of their morphodynamics. This classification is a synthetic description that must later be explained geological and other features.

To test this method, two study sites were selected on the Croatian coast, each characterized by a different lithology. The first coastal cliff is located on the Vrgada Island. Its lithology consists of Pleistocene aeolian-alluvial clastites. The cliff experiences massive episodic rockfalls. The second is the coastal cliff of Duilovo in Split the urban area, which was formed in Eocene flysch. The erosion processes of this soft cliff include rockfalls and rotational landslides.

Study sites

The coastal cliff of Vrgada is located on the island of the same name. It is a ~15 m high cliff consisting of Pleistocene aeolian-alluvial deposits, which alternate from the beach to the top of the cliff [2]. Unlike the north-western gentle slopes, the eastern part of the cliff is a steep vertical slope (90°) more prone to erosional processes. The gravitational processes observed are successive rockfalls [20]. The northern part is an approximately 45° steep slope without obvious gravitational processes, probably due to the dense vegetation [19].

As already mentioned above, Duilovo is part of the Split urban area (Figure 1), where coastal cliffs up to 30 m high have formed. The main rock is Eocene flysch, which in this coastal section is characterized mainly by fine-grained marls with less frequent sandstone layers [21, 26]. Such cliff lithology is susceptible to intense mechanical weathering, especially by water (e.g. rain and surface runoff, ground water leakage, wave abrasion). The entire cliff is steeply sloping (on average about 80°) over its length of ~ 2 km. Such an angle with predominant marl lithology is an ideal place for gravitational processes to occur. The most common gravitational processes are slow wet debris flows and subsequent dry flows of marls previously loosened by surface water. However, rotational landslides occur repeatedly along the western part of the cliff. This section of the cliff was selected for analysis in this work.

In terms of rock hardness, it can be said that the rock mass on the Vrgada Island is slightly more resistant than that of the Duilovo cliff.

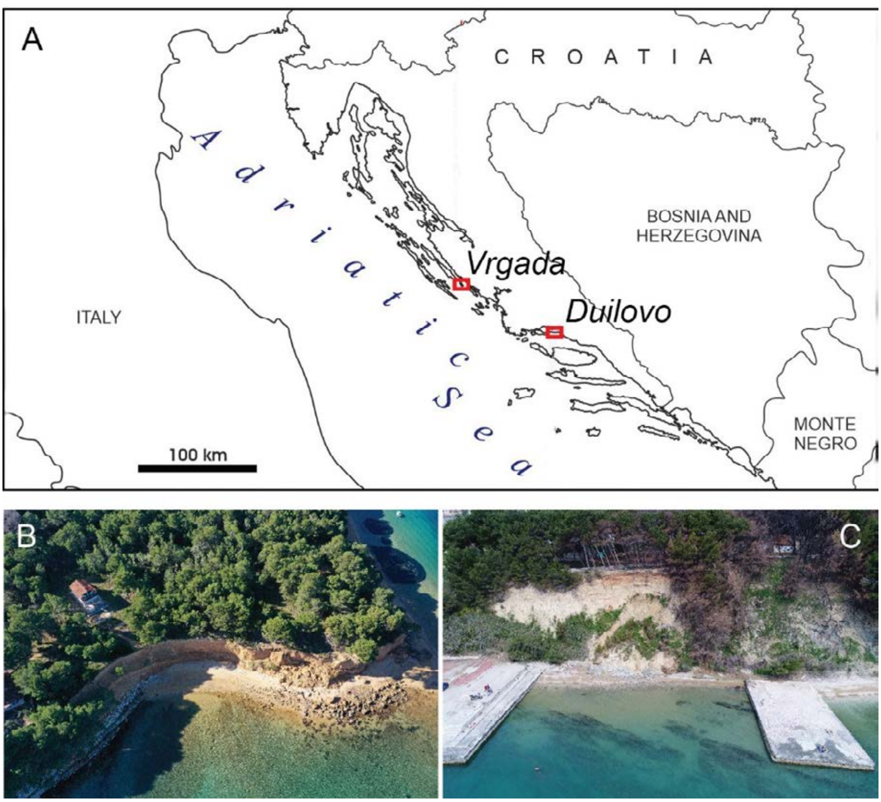

Figure 1 – Location and photographs of the Vrgada and Duilovo cliffs.

Materials and methods

Topographical measurements

The data collection used in this paper for both cliffs was carried out twice: April 2018/May 2018 for the Duilovo cliff and April 2023/June 2023 for the Vrgada cliff. For both study sites, 200 to 400 photos were taken with, both perpendicular to the nadir and at an angle of 45°. The overlap of the photos was 80 % and Structure-from-Motion (SfM) photogrammetry was used with Agisoft Metashape software to post-process the photos (planar orthomosaics) and create digital models (DMs). The DMs were georeferenced using ground control points (GCPs) taken before data collection. The GCPs used were both fixed (painted red dots) and movable (red and white metal plates). Their exact position (3D coordinates) was determined by Virtual Reference Station Real-Time Kinematics (VRS RTK) using a Trimble R8 GNSS receiver and the high-precision positioning service CROPOS (DGU http://www.cropos.hr/). The horizontal and vertical accuracies were within 2 and 4 cm, respectively, while the root mean square error (RMSE) of DMs was within 4 cm. After creation, the orthomosaics and DMs were exported in TIFF format for further processing.

Data processing in GIS

The data set required for the analysis was obtained by processing in a Geographic Information System (QGIS 3.32; Figure 2a).

First, the edges and bottoms of the cliffs were carefully digitised manually on aerial photographs with high spatial resolution (Figure 2b). The edge of the cliff corresponds to the break of the slope. This upper edge is considered as the shoreline as in many other publications on cliffs [4 and references within]. This is a relevant definition for hazard studies as this shoreline is close to potentially endangered infrastructure [3, 7]. The foot of the cliff is another break in slope and it was digitised as a line between debris cones and beach.

Subsequently, the DMs with the elevation data for each study site were converted into a slope map using the QGIS Slope function (Figure 2d).

Data extraction was performed along 5 m spaced transects perpendicular to the shoreline (Figure 2b). They were calculated using Station Lines, an extension of QGIS for calculating transects along a baseline. This baseline can be drawn by hand and must be approximately parallel to the shoreline. The historic shoreline digitised from an aerial photograph can also be used. 11 transects were drawn in Duilovo and 25 transects in Vrgada, along which the positions of respective historical shoreline (April and May 2018 for Duilovo, April and June 2023 for Vrgada) and the positions of the cliff toe were measured.

The change in shoreline was analysed using a classical and widely used geomatic method [8, 23, 25]: the distances between the intersections of a transect and the shorelines were measured.

The QGIS extension qProf was then used to calculate the height and average slope along each transect (more precisely along a segment delimited between the edge and the foot of the cliff at the first date, April 2018 for Duilovo and April 2023 for Vrgada).

Each of these evolutionary and morphological parameters has a significance for the identification meaning of hazard identification. The more rapid the shoreline retreats, the greater the threat to human infrastructure. The higher the cliff, the greater the kinetic energy of a falling block can be. The steeper the slope, the faster mass movement can occur. So, a low cliff would have a slow evolution rate and *vice versa*.

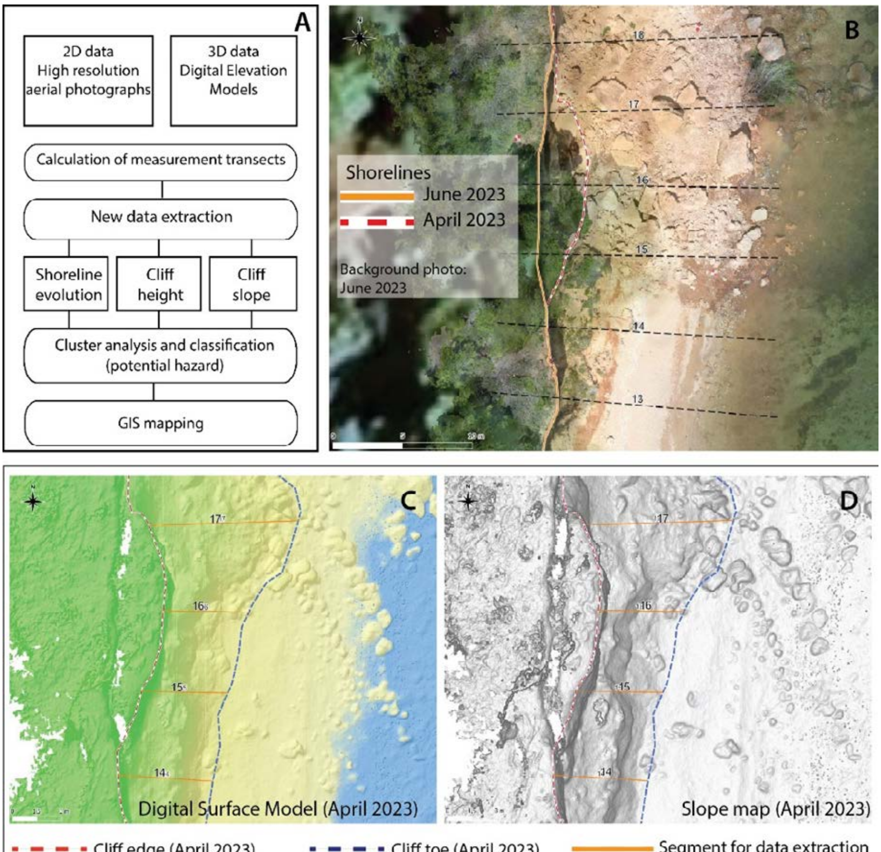

Figure 2 – Methodological chart; examples of shoreline digitization, digital surface model and slope map in Vrgada.

Clustering analysis: data and goals

In a multivariate analysis, a first important question is the hierarchy of the parameters under consideration. In this first classification test, we decided to weight all selected parameters equally. However, since these parameters are expressed in very different units and with very different ranges of variation, it was necessary to standardise them first in order to eliminate the units and ranges of variation. The standardisation process is simple and can be summarised by

Equation 1, where x_s is the standardised value, x_i is the original value at a transect, and $\bar{x}$ is the mean and σ the standard deviation of transects for a parameter for a study site. A standardised value is therefore dimensionless and is the ratio between the comparison of the original value at a transect and the mean value (xi - $\bar{x}$) calculated for all transects, divided by the variability of the values in the statistical series (σ). For example, the slope of a transect is first compared with the mean slope of all the transects in the area and then related to the overall variability.

$$x_s = \frac{(x_i - \bar{x})}{\sigma} \quad (1)$$

The cluster analysis was performed with the latest version of Past 4.17 [12]. This analysis aims to create a typology based on the selected parameters (shoreline evolution, height and slope of the cliff). It can be useful to identify shoreline sections with analogous "behaviours" [1]. At each stage of the calculations, Euclidean distances between each statistical individual (i.e. each transect) were computed. In our case, these are 3D distances (one dimension for each parameter). The shorter the distance, the more similar the entities are. The individuals are gradually grouped into pairs. Sometimes an individual is grouped with a pair that is more similar to it than any other entity. The cluster analysis is presented in a "tree diagram" or dendrogram which showing the stages of progressive aggregation (Figures 3 and 4), with the individuals at the top (the leaves of the tree), the branches below and the trunk at the bottom of the diagram. The discretization threshold is set to a distance chosen so that the main branches of the dendrogram intersect and the desired number of classes is obtained.

Results

Vrgada

The dendrogram shows a fast first step of association of the cliff sectors at a distance of ~ 0.75, which shows their similarity (Figure 3). The very last step of the association takes place at values ~ 5.5, which means that the previously created groups differ significantly. A discretisation threshold can be set at a distance of 2.2. This allows the identification of three classes depending on the increasing distances of association of the groups: a high hazard class in the centre of the area (transects 15 to 17), a medium hazard class comprising the transects in the centre and north; and a low hazard class, comprising the adjacent transects further south of the study area. The small dendrogram on the right side of the colour table above shows that elevation and slope are rapidly linked (Figure 3). This is logical, because in Vrgada cliff is often almost vertical: the higher it is, the steeper the slope can be. Changes in the coastline are less strongly associated with the other two parameters, as the association with the first two parameters occurs later. The colour table helps to perform a more detailed analysis. The colours refer to the small colour scale to the right of the main dendrogram: red indicates a value significantly above the mean

(0 on the standardised scale), blue indicates a value significantly below the mean; green stands for values around the mean (Figure 3). The greater the range of variation, the greater the diversity is. It can be seen that the transects in the low hazard class are characterized by cliff evolution, heights and slopes that are among the lowest (shades of blue), while the transects in the medium hazard class are slightly higher and have steeper slopes (shades of blue, green and light yellow). Transects 15 to 17, which have a higher hazard class, are mainly characterized by strong changes (shades of yellow and red for evolution): the shoreline retreated from 2 to 3.3 m due to a major rockfall during the study period, while the other transects were almost stable. For transects 15 to 17, elevation and slope do seem not appear to be the predominant factors (shades of blue in the colour table).

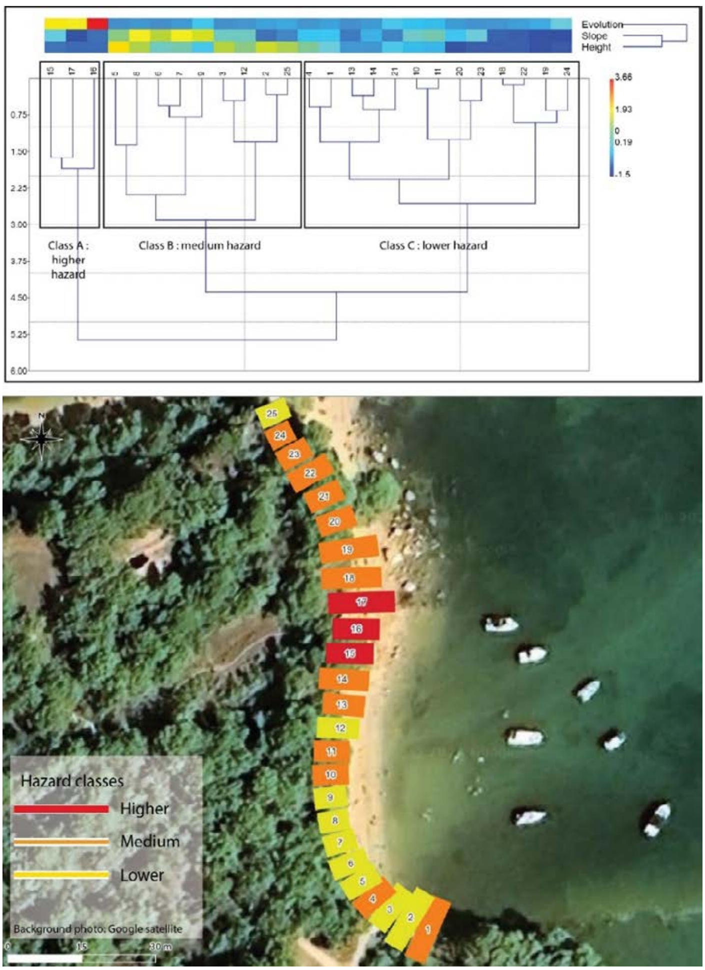

Figure 3 – Dendrogram and classification map for Vrgada.

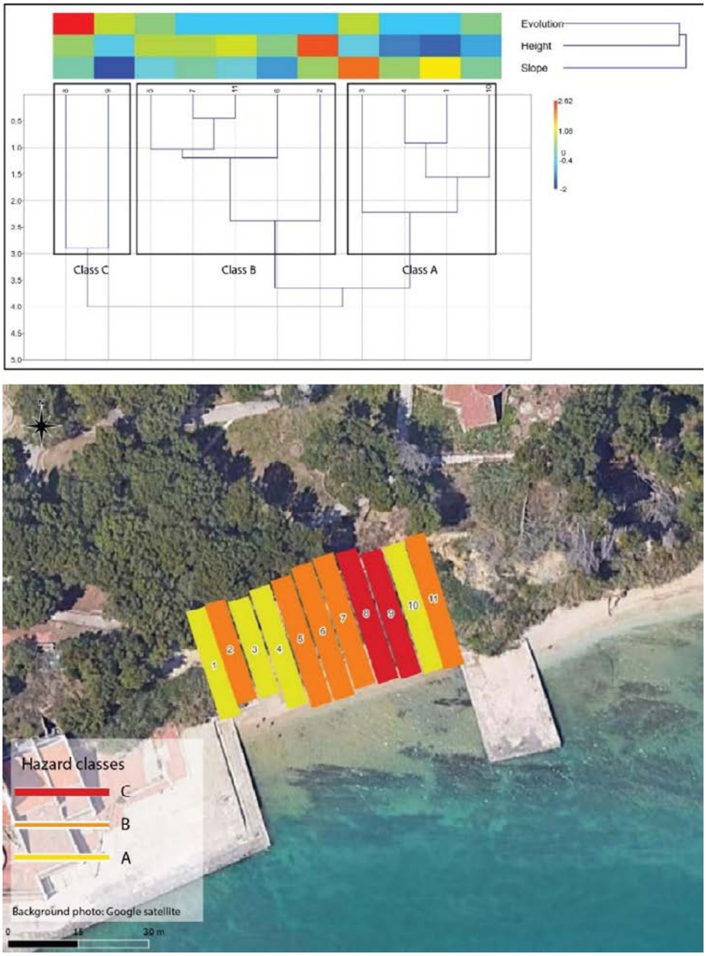

Figure 4 – Dendrogram and classification map for Duilovo.

Duilovo

It is interesting to note that in the Duilovo dendrogram the last level of association occurs at the distance of 3.7 earlier than in the Vrgada dendrogram. This shows that the 11 sectors of Duilovo are relatively more similar than those in the Vrgada dendrogram. This is consistent with the fact that the study area is very small. This is confirmed by the range of variation of the standardised values, which extends from 2.62 to -2 with an amplitude of 4.62 (colours scale in Figure 4), showing that the diversity of cliff conditions is lower than in case of Vrgada (amplitude 5.16). The small dendrogram at the top right shows that in this case, the evolution, elevation, and slope are parameters with a weak relationship: their association occurs late at the end of the dendrogram. In order to create three classes, the discretisation threshold had to be set to a Euclidean distance, i.e. with a larger distance than for Vrgada (2.2). Therefore, there are more relative differences within each class of Duilovo, than within the classes of Vrgada. The colour table helps to interpret the classes that have been created.

We can see that the transects of class A are similar in their evolution and height (green and blue). Only transect 3 (orange) differs slightly in its slope (the steepest in the group). The class B transects are similar in all three parameters. Transect 2 (orange) stands out due to its height (35.8 m, the highest in the class). Transects 8 and 9 of class C are slightly less typical than the others. Transect 9 has a gentler slope (blue), while transect 8 shows a relatively stronger change (red). However, transect 8 shows a very moderate retreat of the shoreline (0.05 m i.e. within the margin of measurement of error), while it is being stable. It is therefore difficult to rank the classes in terms of hazard characterization with this configuration of results.

Discussion and conclusion

The aim of this work was to test the cluster analysis method to describe and classify the level of hazard, using three parameters easy to obtain: cliff evolution, height and slope. This analysis does not require more complex information such as geomechanical parameters [17]. For this purpose, two relatively unknown coastal cliffs on the Croatian coast were investigated. In the case of the Vrgada cliff, the result showed that the highest level of hazard exists along transects 15 to 17, where a rockfall recently occurred. Considering the slopes and heights, which are quite similar along the entire cliff, it seems that other parameters, which were not considered in this analysis, played a more important role for this slope process. For the Vrgada cliff, such parameters could be localised weakness of the rock mass that is the consequence of an existing deep crack, as described in [20]. It was suspected that the intense rainfall in May 2023 was the trigger for the rockfall. After the rockfall, the slope and height of the newly formed cliff face remained mostly unchanged i.e. a steep and vertical slope with an unchanged cliff height. The only exception to the slope is collapsed material, which is eventually washed away. The evolution of the Vrgada cliff is therefore quite simple and involves retreat of the cliff over time without any significant changes in slope and height.

In the case of Duilovo, the cliff evolution shows more complex features, i.e. it was more difficult to explain its evolution based on the index tested in this work. As explained in [21], the vegetation along this cliff plays an important role. It has grown over the slid cliff material. After the rockfall that occurred between April and May 2018, much of the collapsed rock mass was overgrown by vegetation. For this reason, it was very difficult to digitise the position of the two shorelines. As a result, the area with the highest level of hazard (A; Figure 4) was assigned along transects 8 and 9, where the actual vegetation grows and prevents the erosion of the cliff through its roots. On the other hand, a medium-hazard area (B; Figure 4) was designated where landslides and rockfall actually occurred (transects 5, 6, 7). It is assumed that the vegetation cover should be removed from the DM used, and only the digital terrain model (DTM) should be used for the method tested here. Another fact that is not visible and has not been considered in this work is the presence of groundwater breaking out on the surface. Most of this water occurred along transects 5, 6 and 7 where the landslide and the rockfall occurred.

The cluster analysis in the case of Vrgada provided quite understandable results with a higher risk class that stands out from the other two classes and is characterised by an obvious retreat of the shoreline due to a cliff collapse at transects 15 to 17. At the Duilovo cliff, however, the hazard level was much more difficult to determine. The landslide had occurred at transects 3 to 5. It changed the shape and position of the toe of the cliff, but had no impact on the cliff edge. This landslide was not detected by the index used in our method. We suspect that the method is a little too simplistic as the cliff edge was considered as the shoreline, not the cliff toe. Including the cliff toe as a fourth parameter could improve the suitability of the index of the index in the future.

The study periods for our two sites were short. Nevertheless, some remarkable changes in the evolution of the cliffs were detected. In order to examine the applicability of the index in the future, more datasets (new sets of aerial photographs and DEMs) would be useful to rank the hazards and investigate their evolution over time.

The calculated hazard index could also be improved by making it more dynamic by including a temporal dimension for each parameter. Until now, the dynamic dimension was only supported by the shoreline evolution parameter, while the height and slope were calculated for a single date. The evolution of the cliff edge and cliff toe could be calculated using several orthomosaics at different points in time. Changes in cliff heights, slope angles and volume could be considered by comparing multiple DMs.

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MACHINE LEARNING FOR SUSTAINABLE LAND MANAGEMENT: A FOCUS ON ITALY

Matteo Dalle Vaglie, Federico Martellozzo

Abstract: Soil salinization poses a multifaceted challenge demanding a comprehensive approach combining environmental science, machine learning, geography, and socio-economic analysis. Our study integrates these disciplines to unravel the complexities of soil salinization and devise effective mitigation strategies. We ground our investigation in understanding the geological and climatic fundamentals governing soil properties and processes, with a focus on the Mediterranean coastal areas. By harnessing the power of machine learning, we navigate the high-dimensionality and non-linearity of soil salinization, incorporating a comprehensive set of variables spanning geological, climatic, human activity, and socio-economic dimensions. Our models, trained on extensive datasets, are robust and capable of capturing intricate patterns associated with soil salinization. The Mediterranean coastal areas, with their unique ecological, climatic, and anthropogenic interactions, serve as a valuable case study for exploring the dynamics of soil salinization. Our approach integrates data on historical geological changes with current climatic and anthropogenic variables, creating a comprehensive model that encapsulates the temporal and spatial dimensions of soil salinization. This study aims to contribute meaningfully to global efforts in sustainable land management and environmental preservation.

Keywords: salinization, land monitoring, remote sensing, soil management

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Dalle Vaglie Matteo, Martellozzo Federico, *Machine learning for sustainable land management: A focus on Italy*, pp. 707-718, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.61

Introduction

Soil salinization poses a multifaceted challenge that demands a comprehensive and integrated approach, combining diverse disciplines and methodologies to unravel its complexities and devise effective mitigation strategies ((Sparks, 2003; Szabolcs, 1989). Our study nestles within this intricate tapestry, adopting a holistic framework that intertwines environmental science, machine learning, geography, and socio-economic analysis.

We start by grounding our investigation in a robust understanding of the geological and climatic fundamentals that govern soil properties and processes. This involves delving into the morphology and evolution of coastlines and seabeds, as these features play a crucial role in shaping the distribution and dynamics of saline soils (Doula & Sarris, 2016). Coastal areas, with their unique geomorphological characteristics, are particularly susceptible to salinization due to factors such as tidal movements, sea spray, and the intrusion of saline water into freshwater aquifers (Wong et al., 2010). The seabed's topography and composition further influence underwater currents and the transportation of saline water, impacting coastal salinity levels. A nuanced understanding of these geological processes is vital for accurately predicting and mitigating soil salinization in coastal regions (Corwin, 2021). Simultaneously, we extend our analytical lens to incorporate the socio-economic dimensions of soil salinization, recognizing that its impacts ripple far beyond the environmental sphere. This is particularly evident in the Mediterranean coastal areas, where agriculture forms the backbone of many local economies, and the delicate balance of the ecosystem is intricately linked with community well-being (Aung Naing Oo et al., 2013). In these regions, salinization not only degrades soil health but also threatens the livelihoods of farmers, disrupts local food supplies, and exacerbates socio-economic disparities. Our framework, therefore, integrates socio-economic variables and aims to uncover the complex interplay between environmental degradation and social outcomes, providing a holistic perspective on the challenge at hand.

Building on this foundation, we harness the power of machine learning to navigate the high-dimensionality and non-linearity of soil salinization. Our approach is grounded in a thorough understanding of the various factors that contribute to salinization, as well as the intricate ways in which they interact. By incorporating a comprehensive set of variables spanning geological, climatic, human activity, and socio-economic dimensions, we strive to capture the full complexity of the phenomenon (Blum, 2005; Erkin et al., 2019). This not only enhances the accuracy and reliability of our predictions but also enables us to draw nuanced insights that can inform targeted and effective mitigation strategies. The machine learning models serve as a crucial bridge, translating raw data and theoretical knowledge into actionable intelligence. By training our models on extensive datasets, encompassing a wide array of variables and field measurements, we ensure that they are robust and capable of capturing the intricate patterns associated with soil salinization (Hassani et al., 2020). This is particularly crucial for addressing the challenge in Mediterranean coastal areas, where the interplay of natural and human factors creates a unique and complex landscape of soil salinity (Metternicht, 2017). In further enriching our framework, we place a pronounced emphasis on the Mediterranean coastal areas, an epicenter of diverse ecological, climatic, and anthropogenic interactions. The unique characteristics of the Mediterranean climate, marked by hot, dry summers and mild, wet winters, create a distinct environment that is simultaneously rich in biodiversity and vulnerable to soil salinization (Khamidov et al., 2022). The complex interplay of natural elements and human activities in these regions requires a tailored approach, acknowledging the specific challenges and opportunities they present. The Mediterranean basin, with its extensive coastline and intricate seabed morphology, serves as a valuable case study for exploring the dynamics of soil salinization. The region's coastlines have undergone significant changes over geological time scales, shaped by tectonic activities, sea level fluctuations, and sedimentary processes. (Eswar et al., 2021a)These historical transformations have left an indelible mark on the present-day landscape, influencing soil characteristics and salinity patterns. Understanding the evolution of coastlines and seabeds is pivotal in deciphering the spatial distribution of saline soils and predicting their future trends.

Our approach integrates data on historical geological changes with current climatic and anthropogenic variables, creating a comprehensive model that encapsulates the temporal and spatial dimensions of soil salinization. This allows us to identify areas at risk, anticipate potential changes, and formulate proactive mitigation strategies. The Mediterranean coastal areas, with their complex interplay of natural and human-induced factors, offer a valuable context for testing and refining our models, ensuring their robustness and applicability across diverse settings. Human activities, particularly agriculture, urbanization, and tourism, have exerted substantial pressure on the Mediterranean region's natural resources, exacerbating soil salinization. Intensive agricultural practices, relying heavily on irrigation, have led to the mobilization of salts and their accumulation in the soil. Urban sprawl and tourism-related infrastructures have altered natural drainage patterns, further contributing to the salinity issue (Parihar et al., 2015).Our framework explicitly accounts for these human-induced factors, recognizing their critical role in shaping soil conditions and their potential as leverage points for intervention. In encapsulating these diverse elements, our framework adopts a multidisciplinary and multiscale perspective, recognizing that soil salinization is a complex phenomenon influenced by an array of factors operating at different spatial and temporal scales. By integrating geological, climatic, anthropogenic, and socio-economic data, we create a rich and nuanced understanding of the phenomenon, enabling us to capture its multifaceted nature and devise effective mitigation strategies (Tran et al., 2021).

Our holistic and integrative approach, grounded in a deep understanding of the natural environment and enriched by socio-economic insights, positions us to tackle soil salinization in all its complexity. The Mediterranean coastal areas, with their unique challenges and opportunities, serve as a valuable laboratory for refining our models and strategies, ensuring their relevance and effectiveness in diverse settings. Through this comprehensive framework, we aspire to contribute meaningfully to global efforts in sustainable land management and environmental preservation, safeguarding the soil that sustains us all.

Materials and Methods

This study employed a comprehensive and robust dataset, totalling 43594 observations, drawn from the ISRIC-WISE Harmonised Global Soil Profile Dataset (WISE version 3.1). To ensure the reliability and uniformity of the data, stringent inclusion criteria were applied. Only measurements of electrical conductivity in saturated paste were considered, while observations under different dilution ratios (1:1, 1:2, 1:5, and 1:10) were excluded due to their potential to alter the ionic strength and composition of the soil solution (Wong et al., 2010).

Figure 1 – Geographic Distribution of Ece Input Observation

Each observation included information on the year, exact location, and upper and lower depths of the soil sample. Observations with missing data were excluded, and data collected before January 1980 were disregarded to ensure consistency with environmental data collection standards and predictor availability. The dataset encompassed 44 environmental predictors, reflecting a broad range of factors essential to understanding the intricate process of soil salinization. These predictors included geomorphological, hydrogeological, meteorological, soil composition, land use patterns, and variables related to sea level rise and drought prevalence (Corwin, 2021).

The predictors were sourced from various datasets, including detailed maps of soil and lithology, atmospheric reanalysis records, terrain elevation data, comprehensive climate datasets, and outputs from advanced hydrological models. This multifaceted approach allowed the development of a predictive model linking environmental factors with soil profile data. Data quality was rigorously screened, with 363 observations removed due to null values. In cases where null values resulted from geographical discrepancies, the closest predictor value within a two-cell radius was sampled to ensure spatial accuracy (Blum, 2005; Sparks, 2003).

Models	R2
Multiple Regression	0.23
Elastic Net	0.47
SVM	0.62
Random Forest	0.75
LightGBM	0.83
CatBoost	0.82
Neural Network	0.69

Figure 2 – R^2 of the different trained models.

The predictive model utilized 44 global predictors, categorized into static and dynamic types. Static predictors, which remain constant over the study period, included geomorphological factors and soil texture, derived from the Multi-Error-Removed Improved-Terrain (MERIT) DEM and the International Soil Reference and Information Centre (ISRIC) global gridded soil information. Dynamic predictors, which exhibit spatiotemporal variability, primarily comprised climatic, hydrologic, and surface vegetative variables from the CHELSA climatic reanalysis dataset. Non-autoregressive variables were aggregated into annual means and five-year moving averages, while autoregressive predictors considered yearly means due to their continuity over time (Erkin et al., 2019; Wang et al., 2020a). All raster predictors were reprojected in Mollweide Equal Area projection (EPSG:54009), and ECe observations were matched with corresponding predictor values by geographic coordinates and year. Missing values for remotely sensed variables were filled using five-year moving averages of the closest available years, while other variables, produced only in certain years, were matched with the nearest year available (Hassani et al., 2020; Metternicht, 2017). The regression and classification models for predicting ECe values were trained in Python using Pandas, Geopandas, Scipy, Sklearn, LightGBM, and XGBoost libraries. Models were trained using RandomizedSearchCV, evaluating 20 different hyperparameter combinations with 2-fold cross-validation. This method balanced computational speed and efficiency, capturing the variance of the phenomenon with larger datasets. Gradient Boosting trees, specifically CatBoost, LightGBM, and XGBoost, were found to outperform other frameworks in terms of speed, accuracy, and flexibility, with LightGBM ultimately selected for its overall effectiveness (Tran et al., 2021a).

To address the left skewness of the target variable, a natural logarithm transformation was applied to ECe, and a two-level model approach was adopted. This involved initially classifying soils as saline or non-saline and then applying separate regression models to each class. The optimal threshold for classification was determined through extensive testing, with the highest R^2 value achieved at an ECe threshold of 2.

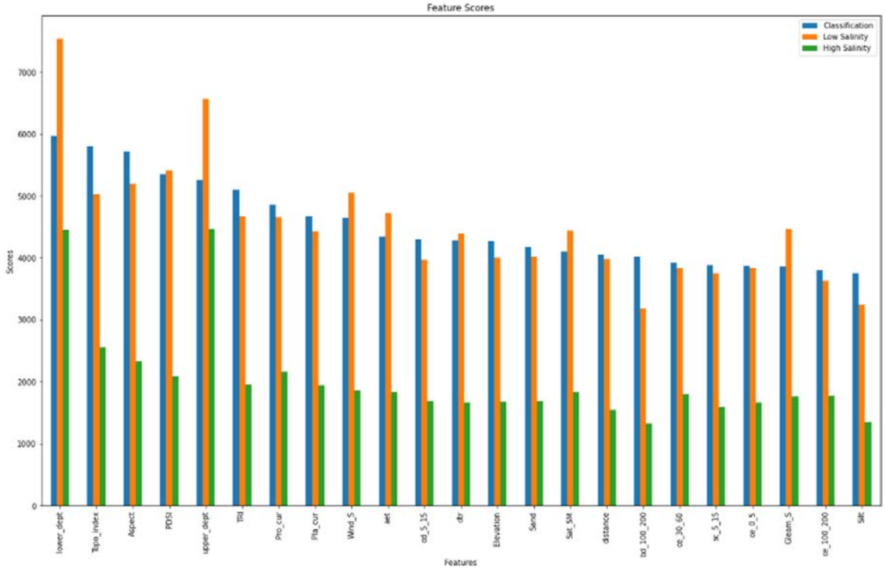

Figure 3 – Bar Chart of the 23 most important variables.

Feature selection was performed iteratively, removing the least significant variable at each step based on the cumulative feature score. This process reduced the predictors from 44 to 21, improving the model's R^2 to 88%. The final model, capable of predicting ECe values with high accuracy, was used to generate global high-resolution maps of soil salinity across various depths and time frames, demonstrating its utility in understanding and managing soil salinization (Eswar et al., 2021; Khamidov et al., 2022; Parihar et al., 2015).

Results

The results of our comprehensive study on soil salinization, particularly focusing on global landscapes with an emphasis on the Mediterranean coastal areas, unveil a nuanced and multifaceted understanding of the phenomenon. By leveraging advanced machine learning algorithms and incorporating a diverse set of variables encompassing geological, morphological, climatic, and human-induced factors, our research provides unparalleled insight into the patterns and drivers of soil salinity. One of the pivotal findings of our research is the identification of key variables and their interactions that significantly influence soil salinity levels. Geological and morphological factors such as soil type, topography, and historical shifts in coastlines and seabeds emerged as crucial determinants (Doula & Sarris, 2016).These factors, deeply rooted in the region's geological history, have set the stage for the current distribution of saline soils. The Mediterranean's unique climate, characterized by distinct wet and dry seasons, further exacerbates soil salinity, particularly in coastal areas where evaporation rates are high, and freshwater inputs are limited (Corwin, 2021). The study also sheds light on the significant role of human-induced activities in shaping soil salinity patterns. Agricultural practices, urbanization, and tourism have been identified as major contributors, with irrigation practices in agriculture being a double-edged sword. While essential for crop production in arid and semi-arid regions, improper management can lead to waterlogging and the mobilization of salts, exacerbating soil salinity (Parihar et al., 2015). Our findings indicate a pressing need for sustainable land management practices that balance agricultural productivity with soil conservation.

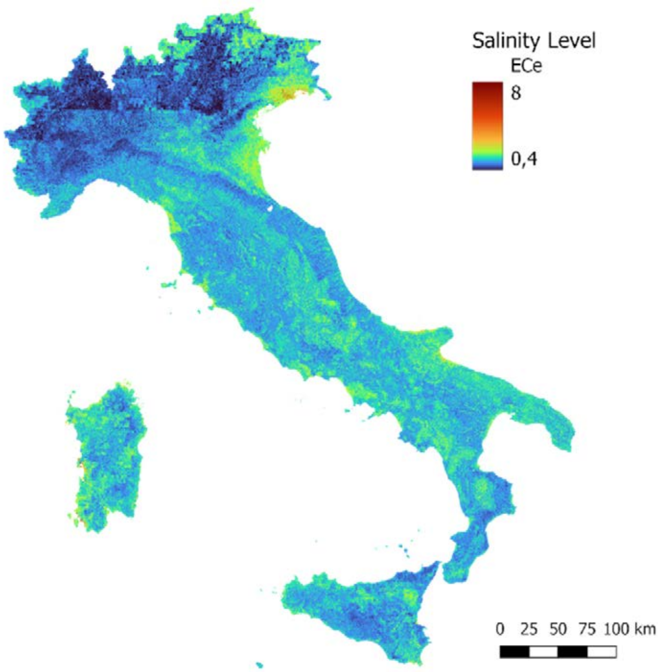

Figure 4 – Soil Salinity Map for Italy (dS/m).

In terms of spatial distribution, our research reveals a heterogeneous pattern of soil salinity across the Mediterranean region, influenced by a combination of natural and human-induced factors. Coastal areas and river deltas were identified as hotspots, bearing the brunt of salinity stress (Eswar et al., 2021a). These findings underscore the importance of targeted interventions and tailored strategies to address soil salinity in these vulnerable regions.

The temporal analysis of soil salinity trends reveals a concerning escalation of the phenomenon correlated with climatic changes and intensified human activities. The increase in global temperatures and changes in precipitation patterns due to climate change have led to an amplification of soil salinity levels, particularly in arid and semi-arid regions (Hassani et al., 2020; Khamidov et al., 2022). This has significant implications for agricultural productivity, biodiversity, and the overall resilience of ecosystems. Our machine learning models proved to be highly efficient and accurate in predicting soil salinity levels, demonstrating their potential as valuable tools for policymakers and land managers. These models facilitate the anticipation of salinity trends, enabling proactive measures and informed decision-making. For instance, the model's ability to predict soil salinity levels in Italy, as depicted in the figure below, highlights areas of high salinity risk that require immediate attention and intervention.

Discussion

Our study's findings underscore the intricate interplay of natural and anthropogenic factors driving soil salinization, with significant implications for agriculture, especially in regions like the Mediterranean. The escalating soil salinity in these areas is a direct threat to agricultural productivity, food security, and socio-economic stability. The Mediterranean region, with its unique climatic conditions marked by hot, dry summers and mild, wet winters, is particularly vulnerable to soil salinization. The combination of high evaporation rates and limited freshwater input exacerbates salinity levels, severely impacting soil health and crop yields (Reed et al., 2022).This poses a critical challenge for local agriculture, which relies heavily on the delicate balance of these ecosystems. Salinization reduces soil fertility, hampers plant growth, and diminishes crop productivity, leading to substantial economic losses for farmers. Human activities further compound this issue. Intensive agricultural practices, especially those involving improper irrigation techniques, contribute significantly to soil salinity. The over-reliance on irrigation in arid and semi-arid regions mobilizes salts, which accumulate in the soil over time (de Ruig et al., 2019). This not only degrades soil quality but also affects water resources, as saline water leaches into freshwater systems. The economic repercussions are severe, with affected regions experiencing decreased agricultural output, increased costs for soil reclamation, and losses in farm income.

In the Mediterranean, agriculture is a cornerstone of local economies, and the impacts of soil salinization extend beyond the environmental sphere. The degradation of soil health threatens the livelihoods of farmers, disrupts local food supplies, and exacerbates socio-economic disparities. For instance, in areas like California, annual revenue losses due to soil salinization amount to approximately 1.0 to 1.2 billion $ (Welle & Mauter, 2017). Similarly, in Northeast Thailand, soil salinity severely impacts rice productivity, leading to food insecurity and economic stagnation in vulnerable communities (Katarzyna Negacz et al., 2022a). Our predictive models highlight the urgent need for sustainable land management practices. By identifying areas at high risk of salinization, our models can inform targeted interventions. Strategies such as improved irrigation management, the use of salt-tolerant crop varieties, and the implementation of crop rotation systems can mitigate the impacts of salinization. These measures not only enhance soil health but also ensure the long-term viability of agricultural lands.

Figure 5 – Salt Affected agricultural soil.

Moreover, the role of policy and governance is crucial in addressing soil salinization. Effective policies that promote sustainable agricultural practices, support research and innovation, and provide resources for soil reclamation are essential. Investing in education and training for farmers on best practices for soil and water management can further bolster these efforts (Ataie-Ashtiani et al., 2013). The integration of machine learning models in our study demonstrates their potential in providing actionable insights for policymakers and land managers. These models offer a robust framework for predicting soil salinity trends, enabling proactive measures to safeguard agricultural productivity. By translating complex environmental data into practical solutions, our approach contributes to the broader goal of sustainable land management and environmental preservation (Linke et al., 2019; Vousdoukas et al., 2016).

Conclusion

Our study on soil salinization underscores the urgent need for comprehensive strategies to address this escalating environmental challenge. The integration of advanced machine learning models with extensive datasets has provided deep insights into the complex interplay of natural and human-induced factors driving soil salinity. This multifaceted approach is crucial for developing effective mitigation strategies tailored to the unique characteristics of affected regions, particularly the Mediterranean coastal areas (Katarzyna Negacz et al., 2022b).

The findings reveal that both geological and climatic factors, along with human activities such as intensive agriculture, urbanization, and improper irrigation practices, significantly contribute to soil salinization. This poses a severe threat to agricultural productivity, food security, and socio-economic stability. The Mediterranean region, characterized by its distinct climatic conditions and high dependency on agriculture, is particularly vulnerable (Perri et al., 2020). Soil salinization in this area not only degrades soil health but also threatens the livelihoods of farmers and disrupts local economies. Our predictive models highlight the importance of targeted interventions to manage soil salinity. Sustainable land management practices, including improved irrigation techniques, the use of salt-tolerant crops, and crop rotation systems, are essential to mitigate the adverse impacts. Policymakers play a pivotal role in this process, requiring the development of robust policies that promote sustainable agricultural practices, support research and innovation, and provide resources for soil reclamation. Investing in education and training for farmers on best practices for soil and water management is also crucial (Eswar et al., 2021b; Haj-Amor et al., 2022). This not only enhances the effectiveness of mitigation strategies but also ensures the long-term viability of agricultural lands. Moreover, our study demonstrates the potential of machine learning models in providing actionable insights for land managers and policymakers. These models facilitate the prediction of soil salinity trends, enabling proactive and informed decision-making.

In conclusion, addressing soil salinization is a complex but essential task that demands a holistic and integrative approach. By combining scientific understanding with technological innovation and effective policy interventions, we can mitigate the detrimental effects of soil salinization. This will protect agricultural productivity, ensure food security, and enhance the resilience of ecosystems and communities, particularly in the Mediterranean region. Our comprehensive framework and findings contribute significantly to global efforts in sustainable land management and environmental preservation, paving the way for a more resilient and sustainable future (Tran et al., 2021b; Wang et al., 2020b).

Acknowledgement

We would like to extend our sincere gratitude to all the individuals and institutions that contributed to the success of this research. Special thanks to the European Fund for their support through the SALAD (Saline Agriculture for Adaptation) project, which provided invaluable resources and funding for this study. The insights and data gathered through the SALAD project were instrumental in advancing our understanding of soil salinization and developing effective mitigation strategies. We also appreciate the collaborative efforts of our colleagues and partners, whose expertise and dedication were crucial in achieving the objectives of this research.

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MONITORING BEACH EROSION ALONG THE CENTRAL ADRIATIC COAST: THE CASE STUDY OF MOLISE REGION

Gianluigi Di Paola, Grazia Dilauro, Claudia Caporizzo, Carmen M. Rosskopf

Abstract: Coastal areas characterized by sandy shorelines are among the most dynamic environments and subject to deep and rapid changes over time under the influence of natural and anthropic factors. Therefore, reconstructing the geomorphological and anthropogenic evolution, current state and possible near-future trends of a sandy beach is essential for deepening the understanding of its potential future development and better outlining measures for its sustainable management. For this purpose, we have examined the coast of the Molise region in Italy, which is predominantly made of sandy shorelines and characterized by widespread anthropogenic impact mainly due to tourism and the presence of hard defense structures. This coastline has been continuously and differentially monitored using increasingly modern and efficient approaches and tools over time. We began in the late nineties with traditional topographic instruments and later transitioned to high-precision tools such as GNSS and drones. Field measurements mainly concerned shoreline and dune front positions along with sedimentary and morpho-topographic features of both the backshore/foreshore zones and the submerged beach up to the closure depth, allowing for their large-scale analysis and data updating over time. More recently, drone survey campaigns, carried out along strategic or critical coastal stretches between 2019 and 2024, allowing for the rapid creation of digital terrain models and detailed and punctual evaluations of recent morpho-topographic changes of the beach-dune systems. The combination of all validated field survey methodologies, along with the planned campaigns for the near future, represent the monitoring plan outlined for the Molise coast aimed at defining future action strategies to support its sustainable development and the mitigation of the effects associated with the ongoing climate change.

Keywords: Shoreline changes, natural and anthropogenic controls, coastal monitoring techniques, climate change.

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Gianluigi Di Paola, Grazia Dilauro, Claudia Caporizzo, Carmen M. Rosskopf, *Monitoring beach erosion along the Central Adriatic coast: the case study of Molise Region*, pp. 719-729, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.62

Introduction

Low-lying coastal areas are among the most dynamic environments and particularly sensitive to climate change. They are undergoing worldwide deep and rapid changes over time that can significantly modify their entire morphological structure and equilibrium, and subject to increasing anthropization due to growing tourist activities and the expansion of inhabited centers. To deepen the understanding of the current state and potential future development of a coastal area, the reconstruction of its long to short-term geomorphological and anthropogenic evolution, together with the assessment of possible near future trends, assume a crucial importance. While extensive literature exists on the morphodynamics of natural beaches and their response to wave climate variations or sea level rise (e.g. [10, 18]), fewer studies delve into how beaches morphologically respond to the presence of coastal structures or nourishment interventions (e.g. [14]). Coastal monitoring emerges as an essential instrument for this purpose, indispensable for supporting management and decision-making endeavors, particularly in light of climate change and its associated impacts [3]. Monitoring methodologies can vary, contingent on factors such as duration, spatial coverage, precision, spatial-temporal resolution, and associated costs [5, 16].

For this purpose, the Molise Region coast that represents a typical example of low-lying sandy coast and is characterized by an important anthropogenic pressure mostly related to tourism activities, has been examined

As evidenced by Buccino et al. (2020) [4] and Rosskopf et al. (2018) [17], the Molise coast has experienced intense erosion since the early 1900s that first caused the complete erosion of the Trigno and Biferno deltas, then a more extensive shoreline retreat, and a consistent loss of coastal land in the last 65 years. Shoreline retreat mainly affected the coastal stretches including the Trigno and Biferno mouths but did not spare several other coastal portions in different periods. To contrast further shoreline retreat, hard defense structures, mainly adherent and detached breakwaters, and groins, have been built especially from the 1980s up to 2000. Nevertheless, erosion partly further accelerated its pace over the last twenty years, with the increasing involvement of coastal stretches located south of major river mouths, and peak rates recorded between 2012 and 2019 for the Biferno mouth area [11].

Materials and Methods

The data that gradually emerged from several studies on the shoreline evolution and recent shoreline trends of the Molise coast (see references in Di Paola et al., 2023 and Rosskopf et al., 2018 [11, 17]) highlighted its elevated present-day and near-future fragility suggesting a more detailed monitoring to better understand ongoing dynamics and prevent future degradation. To this purpose, we started to carry out several and different monitoring activities since 2001. In detail, monitoring activities include the realization and analysis of beach profiles appropriately positioned along the coast and connected to an equal number of bathymetric profiles extending up to the closing depth and the periodical sediment sampling both in the emerged (backshore and foreshore) and submerged beach zones. Furthermore, the assessment of shoreline and dune foot positions, as well as of defense structures through topographic data acquired in the field, photogrammetric data and UAV derived data, and, finally, the characterization of the wave climate conditions and related changes over time, are part of them.

Figure 1 provides a detailed view of the Molise coast monitoring, highlighting the interplay between the different tools used to assess various coastal elements.

It should be noted that the monitoring activities concerning the sedimentology of the emerged beach, and the morphology of the submerged beach are not addressed in this study for the sake of brevity. However, they have been included in the scheme in Figure 1 to provide a clear overview of the work undertaken along the Molise Region coast.

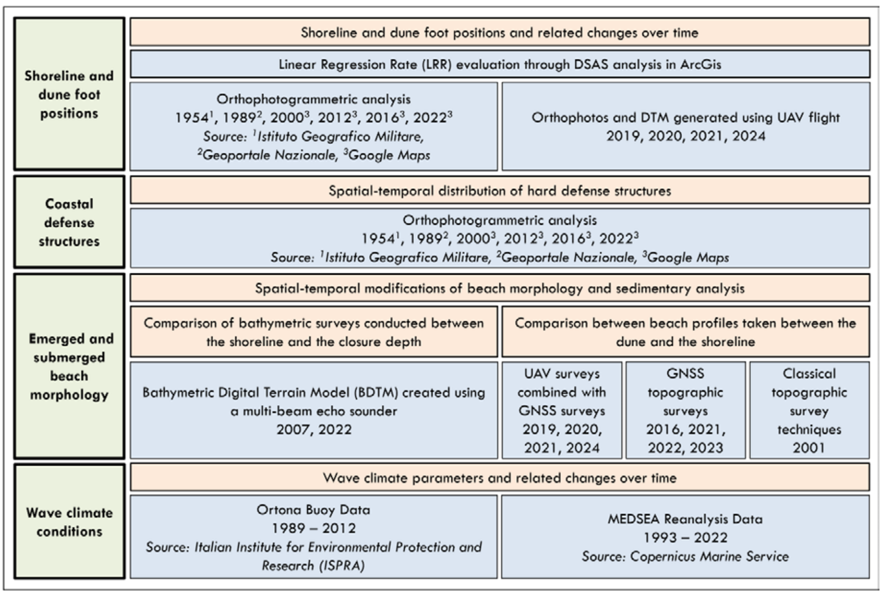

Figure 1 – Flow chart of coastal monitoring of the Molise Region coastline

Shoreline and dune foot positions

In this study the shoreline is defined as the boundary between the dry and wet areas of the beach, while the dune foot is positioned where the beach passes landwards to embryonic dune vegetation or, in areas with intense erosion, at the base of the scarp cut by erosion into the dune front [1, 7, 8]. To evaluate these elements, we used orthophotos from different years covering the entire Molise coastline, along with photogrammetric images and DTMs obtained from drone surveys for more fragile areas (Figure 1). To assess shoreline and dune foot changes, we used the Digital Shoreline Analysis System (DSAS), a freely available ESRI's ArcGIS extension [12]. This tool, by automatically creating regularly spaced transects, provides the Linear Regression Rate (LRR) parameter that represents the average rate of accretion or erosion, which is obtained after fitting a least-squares straight line to each shoreline section for each considered period. In detail, shoreline variations were determined for the whole Molise coast by using 352 transects placed at an equidistance of 100 m. For areas requiring more detailed analysis, a transect spacing of 5 meters was chosen.

Coastal defense structures

The Molise coast is characterized by the widespread presence of hard defense structures that often have been constructed in emergency conditions, i.e. without considering the sedimentary dynamics of the shoreline. As highlighted by several studies (e.g. [4, 17]), these structures have often resulted to be inefficient over time and/or responsible for significant negative effects on adjacent areas. To analyze the spatial-temporal distribution of defense structures, a morphometric analysis was performed in a GIS environment by examining a set of orthophotos and aerial photos taken in different years (Figure 1). Photointerpretation allowed the implementation of a database containing information about types and periods in which defenses were constructed, modified or removed. The identified structures are represented by adherent and detached (submerged and emerged) breakwaters, and by groins.

Beach morphology and sediment features

Another aspect for the thorough analysis of the study coast is the characterization of its morphology, achieved through beach and bathymetric profiles. In detail, beach profiles were traced orthogonally to the shoreline, starting at least from the crest of the dune that marks the landward limit of the backshore, while bathymetric profiles were realized between the shoreline and the closure depth. The beach morphology and related recent changes were investigated over the last 20 years (Figure 1). To realize beach profiles, we initially used a classical methodology based on the use of a theodolite and a grade rod, and afterwards a Global Navigation Satellite System (GNSS) that allowed a faster data acquisition. In recent years, these methodologies were integrated using Digital Terrain Models (DTMs) derived from drone surveys. Data obtained by combining over time such different methods were correlated to assess their reliability, which was proved to be extremely high [15]. The bathymetric profiles were conducted during the summers of 2007 and 2021 using a single-beam echo-sounder along transects created every 200-250 meters, which reached up to 600 meters from the coastline and an average depth of 10 meters below sea level. Periodically, morpho-topographic and morpho-bathymetric surveys were integrated with sedimentological analysis of both the emerged and submerged beach, to assess changes in sediment features and grain sizes along the entire coastal strip.

Wave climate parameters and related changes over time

To characterize the wave climate along the study area, it was necessary to acquire a statistically significant time series of data representative of the incident wave conditions [4, 6]. Both directly measured wave parameters and indirect wave data derived from models simulating wave types based on wind direction and energy (Figure 1) were acquired. In detail, wave parameters recorded by the directional wave buoy located offshore of Ortona at about 56 km north of the Termoli harbour were obtained, including 3-hourly data concerning significant wave height, peak period, and azimuth of the mean wave direction recorded during the period 1989–2012. Wave heights and periods were adjusted by using a virtual buoy located offshore of the coast of Termoli. To integrate the "buoy dataset" of Ortona, the time series with a one-hour interval of significant wave height, mean wave direction, and peak wave period from the "MEDSEA Reanalysis" dataset were acquired for the period from 1993 to 2021 and considered representative for the offshore marine conditions of the investigated physiographic unit [13]. This dataset is based on the WAM (WAve Model) that provides hourly instantaneous data of spectral wave parameters calculated on a grid with a resolution of approximately 4.6 km, covering the Mediterranean Sea and an adjacent portion of the Atlantic Ocean.

Results and Discussion

The multi-instrumental monitoring implemented on the Molise coast has enabled its accurate and diversified analysis, allowing for the characterization of the evolution of numerous morphological elements defining it. Most of the data produced until to date, used to study more general or specific aspects of the Molise coastal system are summarized in the works of Aucelli et al. (2009; 2018) [1, 2], Rosskopf et al. (2018) [17], Buccino et al. (2020) [4], Minervino et al. (2022) [15], and Di Paola et al. (2022; 2023) [8, 10]. This paper presents the general results of this monitoring approach with an in-depth analysis concerning the emerged beach.

The shoreline changes of the Molise Region from the 1950s to the present have been thoroughly investigated, distinguishing long, mid and short-term periods. In the long run (Figure 2A), shoreline retreat affected especially the coastal sectors including the Biferno and Trigno river mouths, with average retreat rates of up to 5 m/year during the last 68 years (Figure 2B, period 1954-2022). Considering instead recent years, data show that increasingly severe erosion affected above all areas close to defense structures, as shown by analyzed data concerning the period 2012-2022 (Figure 2C). The observed relation between the position of defense structures and major erosion hot spots highlights the importance of an accurate and detailed inventory of defenses to understand their impact on coastal dynamics. Data collected show that the coverage percentage of coastal defense structures along the Molise coast increased from 29 % to 62 % between 1989 and 2022 (Figure 2).

The effects of defense structures can only be understood by analyzing in detail the wave climate that characterizes the coast. Specifically, the monitoring carried out over time has shown that the Molise coast is characterized by relatively mild meteomarine conditions, due to its limited fetch and rather moderate wind settings. In fact, 83.5 % of the recorded sea states have a significant wave height of less than 1 m, and only 3.4 % of them correspond to marine storms, assuming that a storm is characterized by a significant wave height greater than 2 m. Furthermore, the waves approach the Molise coast from two prevailing directions: the directional quadrant between NW and NE, and the directional sector approximately from NE to SE, significantly influencing coastal evolution.

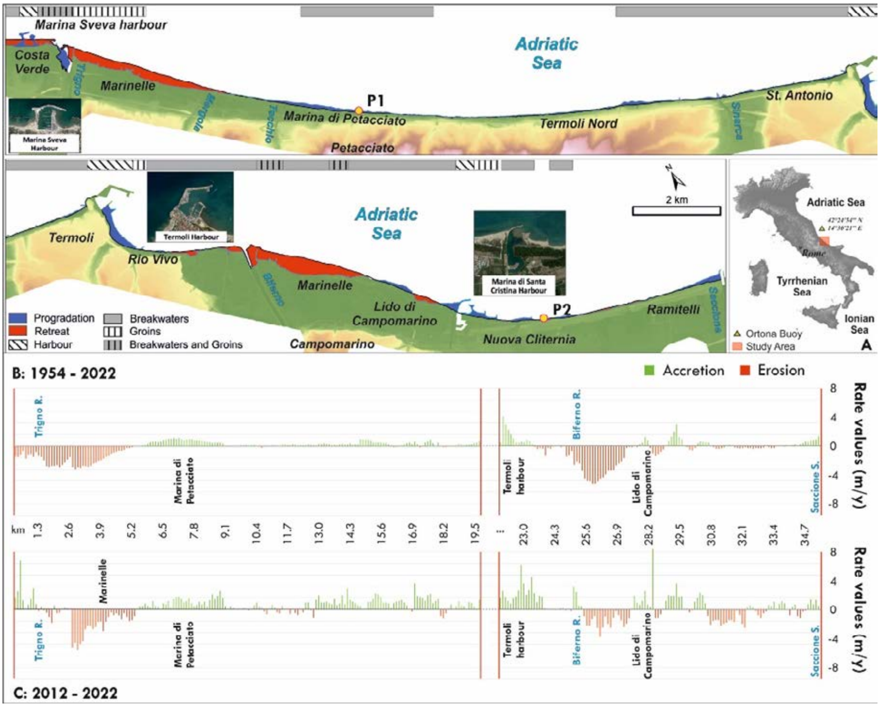

Figure 2 – A: Distribution of progradation and retreat along the Molise coast in the long-term period (1954-2016), extension and location of coastal defense structures and harbours (modified from Di Paola et al., 2020 [9]). B and C: evolution of the Molise shoreline evaluated with DSAS respectively over the long-term (1954-2022) and the short-term (2012-2022).

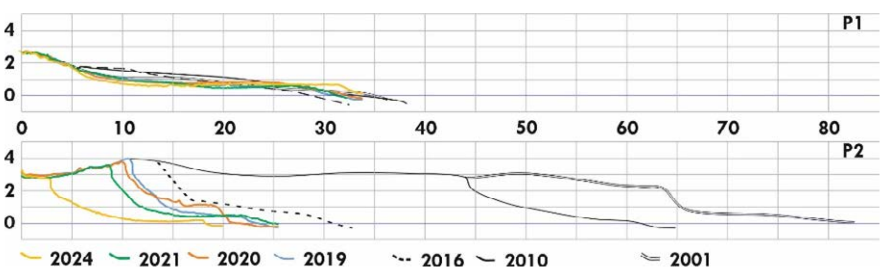

Figure 3 – Comparison between the profiles surveyed from 2001 to 2024 along the beaches of Petacciato (P1) and Campomarino (P2).

The beach morphology is under detailed investigation since 2001. Various instruments were used for its monitoring, as previously described. Figure 3 shows two sequences of profiles realized between 2001 and 2024 in two selected beach stripes, located respectively in the territories of Petacciato and Campomarino. Data were acquired first with a traditional instrumentation, then continued with the use of GNSS technique in 2016 and 2010, and from 2019 onwards with UAV surveys.

The beach profiles of Petacciato beach (P1, Figure 3) evidence an overall substantial stability of both the shoreline and the dune front positions.

The profiles of Campomarino beach (P2, Figure 3), instead, show a very strong erosive trend with a shoreline retreat of about 63 m from 2001 to 2024 (2.7 m/year) accompanied by a dune front retreat of 61 meters, so that the beach remained essentially stable in width over this period.

The main details about the most recent trends of the Campomarino and Petacciato beaches are shown in figures 4 and 5 displaying the orthophotos obtained from UAV flights conducted in 2019 and 2024, respectively.

Figure 4 shows that the Petacciato beach has remained essentially stable in the southern portion, showing some slight retreat of the shoreline in the northern portion. Anyway, the dune foot appears on overall stable.

The Campomarino beach instead (Figure 5) appears to be affected by a clear retreat of both the shoreline and the dune front in its central and southern portions.

Comparing these two areas highlights that the dune foot maintains its position in natural and accretion areas (Petacciato beach, Figure 4), while it responds with pronounced retreat in zones with strong erosive dynamics such as the Campomarino, clearly highlighting the erosive impact of wave run-up on it during storm events. It should be added that the dune foot is sometimes also modified by anthropogenic interventions such as beach cleaning that destroys the embryonic dunes and, in some cases, has been even retreated artificially by scrapers to enlarge the beach for bathing purposes.

Conclusions

The present study has illustrated the monitoring protocol developed for the Molise coast aimed at a better understanding of general and local aspects concerning its evolutionary dynamics and recent to possible near-future trends.

The set of performed surveys and analyses has allowed constructing a valid database upgradeable in space and time according to already defined steps and/or future needs. This database can validly sustain future investigations and action strategies aimed at mitigating the effects of ongoing climate changes, therefore contribute to the definition of sustainable management solutions for the development of coastal areas without compromising their geomorphological and ecological equilibrium and quality.

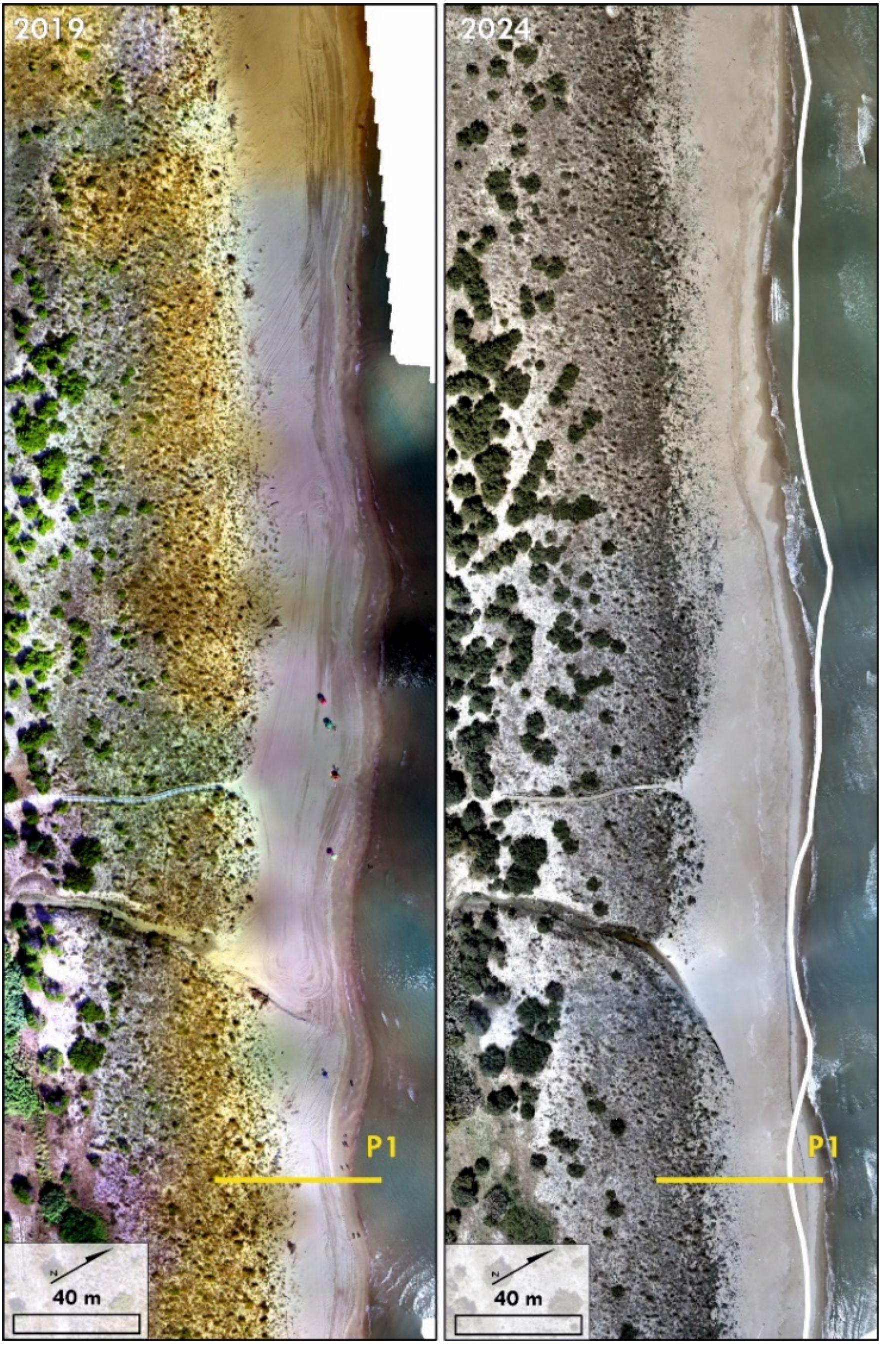

Figure 4 – Comparison between the orthophotos obtained elaborating drone surveys performed in 2019 and 2024 on the Petacciato beach. The 2019 UAV shoreline is marked in white.

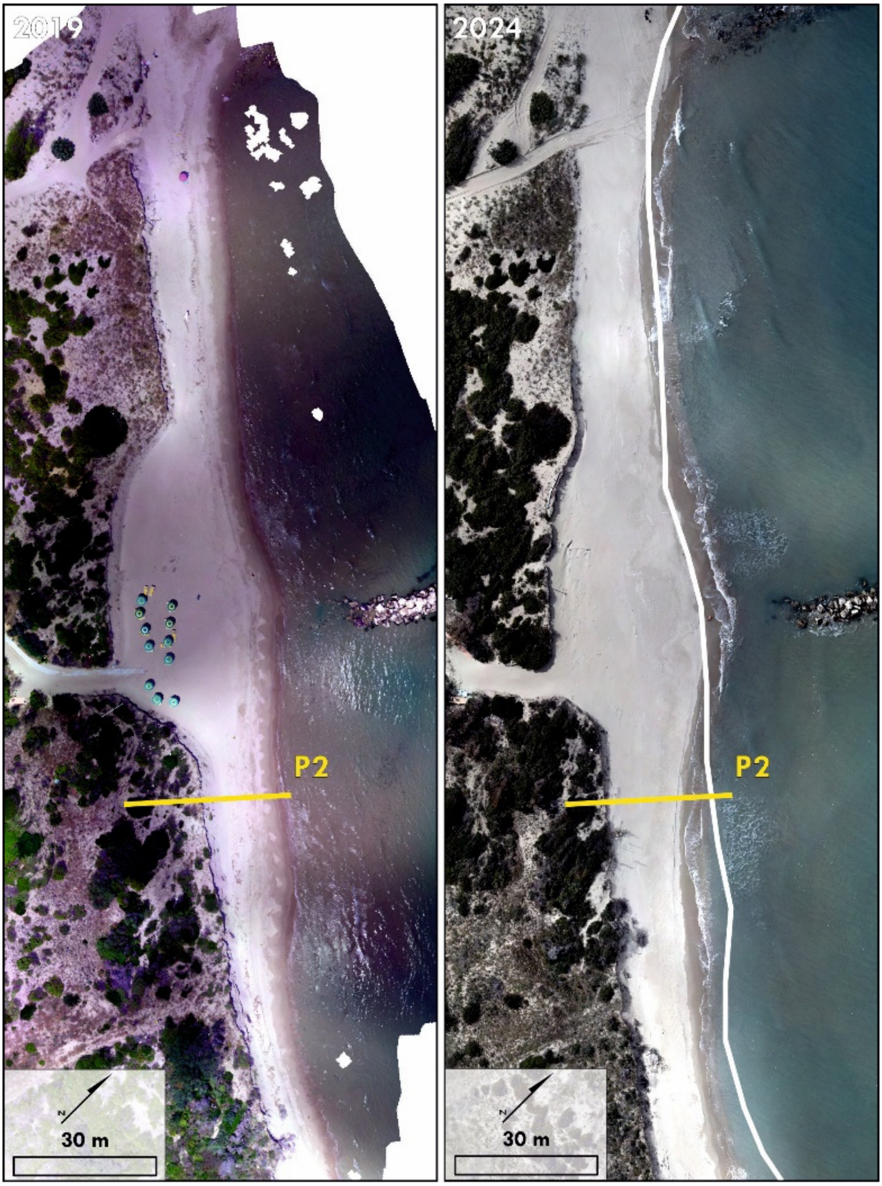

Figure 5 – Comparison between the orthophotos obtained elaborating drone surveys performed in 2019 and 2024 on the Campomarino beach. The 2019 UAV shoreline is marked in white.

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EVALUATING THE IMPACT OF SAND FENCES ON FOREDUNE RECOVERY IN SANT PERE PESCADOR BEACH (COSTA BRAVA, SPAIN)

Carla Garcia-Lozano, Warren Meredith, Maria Marta Tonda, Josep Pintó, Carolina Martí-Llambrich, Ventura Campillo, Francesc Xavier Roig-Munar

Abstract: Coastal dune systems have been significantly altered due to erosion from environmental and human factors, and nature-based solutions have become important in restoring these ecosystems in the face of climate change. The *el Cortal de la Devesa* beach (Gulf of Roses, NE Spain) has been the focus of such nature-based solutions with the installation of sand fences. Two campsites along this beach have implemented contrasting integration strategies over time. The Northern campsite has defined its boundaries and regulated beach access, while the Southern campsite did not. This study aimed to develop high-resolution (10 cm) digital elevation models to quantify changes in sediment retention and dune height both pre and post construction of the fences, to assess differences between the campsites. Results indicated the Northern site had higher overall values in average height, maximum height and volume of sand dunes than in the Southern site. Also, a porosity of 50-60 % proved 85 % efficient in this context. This study contributes objective data that highlights the potential role that tourist-recreational sites play along coastlines in climate change resilience.

Keywords: dune restoration, nature-based solutions, sand fences, rope fences, Catalan coast.

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Carla Garcia-Lozano, Warren Meredith, Maria Marta Tonda, Josep Pintó, Carolina Martí-Llambrich, Ventura Campillo, FrancescXavier Roig-Munar, *Evaluating the impact of sand fences on foredune recovery in Sant Pere Pescador beach (Costa Brava, Spain)*, pp. 730-740, DOI: 10.36253/979-12-215-0556-6.63

Introduction

Coastal dunes are dynamic structures formed by wind-transported sediments accumulating against natural obstacles, primarily plant debris deposited by wave action on elevated beaches. These obstacles reduce wind transport and encourage vegetation growth, leading to the formation of initial dunes that eventually develop into more substantial foredunes. The primary source of these sediments is the beach, where tidal variations and wave dynamics deposit sand, as detailed by [1] and [2]. Dunes are continuously shaped by environmental factors such as wind, water, and human activities. Their formation and characteristics are influenced by local climate conditions, wind patterns, sand availability, and vegetation presence. The global distribution of dunes showcases significant variance in size, from modest hills to expansive areas stretching thousands of kilometers. This diversity is classified based on material characteristics and formation processes, with types including transverse, longitudinal, oblique, linear, and star dunes [3]. Coastal dunes, often smaller than their desert counterparts, are crucial for protecting shorelines from sea level changes and storm impacts, necessitating thorough research and science-based management strategies. As dunes grow, they support more varied plant species, indicating increased dune stabilization. This ecological succession, along with factors such as sand mobility and erosion tolerance, plays a pivotal role in shaping dune landscapes, as described by [4] and [2].

Currently, global dune degradation, driven by tourism and urbanization, underscores the urgency of conservation. In Europe, dune areas have declined by approximately 70 % in the past century, with Catalonia losing nearly 90 % of its dunes [5]. Increased conservation efforts have emerged, exemplified by Spain's legislative measures and the establishment of protected areas. The "European Dune Conference" in 1987 and the formation of the "European Union for Coastal Conservation" highlighted the commitment to dune preservation. One of the recognized methods involves strategic use of sand fences to retain sediment and disrupt wind-driven transport. These structures, ranging from synthetic plastic meshes to natural fabric meshes, are crucial for mitigating wind effects on sediment movement. Their design, particularly porosity and alignment with prevailing winds, is critical for effectiveness, with a general recommendation of 40÷50 % porosity [14].

El Cortal de la Devesa beach (Gulf of Roses, NE Spain) is a 2-kilometer-long beach-dune system that has faced significant tourism pressure and has been the focus of such nature-based solutions. Under a dune restoration project, the installation of sand fences and rope fences was completed in 2020, along with various management strategies to stop mechanical cleaning of the upper beach. This part of the coastline is also entirely encompassed by developed campsites. Within this area, two campsites have adopted contrasting management approaches over time. The Northern campsite has clearly defined its boundaries and regulated beach access. In contrast, the Southern campsite, where management ceased in 2021, has neglected to control beach access, limit mechanical cleaning, and has also been overrun by invasive plant succession. Using unmanned aerial vehicles (UAVs), the objective of this study was to create high-resolution (10 cm) digital elevation models for quantifying changes in sediment retention and dune height before (2019) and after (2023) the construction of the fences. This was done to evaluate variances between the Northern and Southern campsites. By comparing these distinctly managed areas, the aim is to gain a more comprehensive understanding of coastal dune dynamics and to contribute to the development of more effective strategies for their preservation and restoration. A key focus is the challenge of foredune recovery, emphasizing the critical role of management practices in camping areas and visitor behavior. This study also provides empirical evidence, underscoring the significant potential of tourist-recreational sites in bolstering climate change resilience along coastlines. Implementing management strategies with nature-based solutions could improve beach-dune profiles, thus safeguarding coastal users and facilities from the impacts of climate change.

Study Area

The Gulf of Roses is located on the Alt Empordà plain, on the Northern coast of Costa Brava (Catalonia, Spain). El Cortal de la Devesa beach is located in the Southern section of the gulf (Figure 1), where sediment transported by the longitudinal current from the NNE contributes to the formation of the widest beach, spanning between 50 and 75 m in width. Stretching 2 km in length, *el Cortal de la Devesa* beach encompasses a total area of 15 hectares.

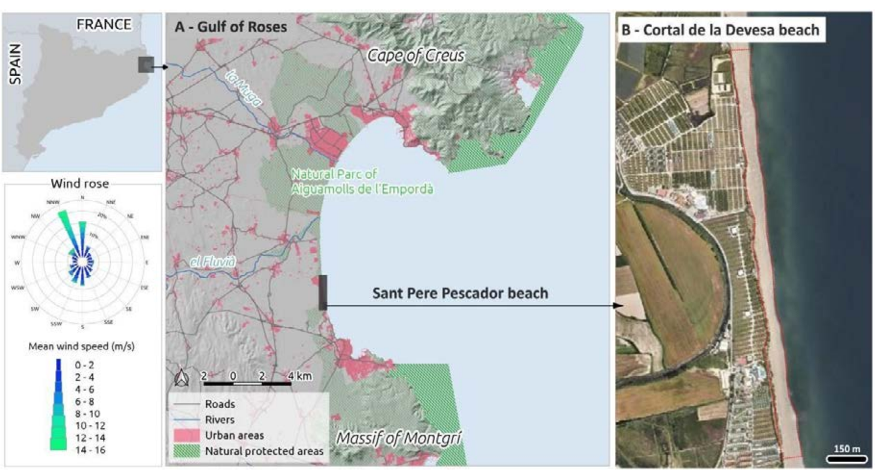

Figure 1 – Study Area: *el Cortal de la Devesa* beach (B) is in the Southern sector of the Gulf of Roses (A), Spain. The precise area under study is indicated with red dots. The 2023 aerial photograph. Source: Cartographic and Geological Institute of Catalonia (ICGC), and Spanish Institute of Oceanography (IEO).

The beach-dune systems in the Gulf of Roses feature transversal dunes, some with parabolic and barchanoid shapes, and foredunes on the upper beach. South of the Fluvià river mouth, the coastline's orientation shifts, enabling *the tramontana* winds from the north to create one of Spain's most significant mobile dune systems [5]. These dunes, devoid of vegetation and crescent-shaped with horns pointing leeward, form under strong winds in sediment-rich areas. The prevailing north-northwest winds push these dunes parallel to the coast, primarily consisting of well-sorted medium and fine sands. The foredunes here are weak and fragmented, marking the transition between the beach and wetlands. The southern Gulf of Roses, facing north, receives sediment from the north via longshore currents, forming smaller barchans. These dunes undergo cycles of destruction and formation multiple times a year due to storm conditions and wind patterns. The inner arms of the barchans play a crucial role in supplying sediment to the foredunes, which are then stabilized by vegetation, delineating the sandy coastal areas from the marshlands.

Materials and Methods

This study investigated the geomorphological changes of the foredune between 2019 and 2023 following the implementation of recovery-oriented management measures (Table 1A). The sand traps constructed in 2020 have dimensions of 10÷15 m in length, with a 50÷60 % porosity and a height of 85 cm, a width between 10 and 15 m each, and orientated NNW (Figure 2).

Figure 2 – Sand fences at the Northern campsite almost completely buried by sand, showcasing the natural accumulation process over time.

Unmanned aerial vehicles (UAVs) with RGB sensors were used to collect data before and after the installation of sand fences. High-resolution (10 cm) digital elevation models (DEM) were generated from the collected data using PIX4Dmatic software which is based on photogrammetric techniques. For high-resolution DEMs, 80 % frontal and 70 % lateral image overlap were used, with a flight altitude of 70 m. Both ground control points and checkpoints were utilized to calibrate the DTMs and assess their accuracy. The checkpoints specifically measured the error in the Z-axis of the DTMs, with the Root Mean Square Error (RMSE) calculated using the Point Sampling Tool plugin in QGIS. This allows us to confirm that we are working with digital topographic models with an average altitude error of 4 cm.

UAV flights occurred in May 2019 and in May 2023, before and after the implementation of management measures. Analyses focused on sediment accumulation, including variations in dune height (Average height (AH), maximum height (maxH), and minimum height (minH)) and volume development (Vol) (Table 1). These variables were calculated from the delimited foredune within each grid block using native tools in QGIS 3.34.1 and ArcGIS Pro.

The criterion for defining the studied foredune area varied according to the beach section and the management measures implemented. Although it always starts from the appearance of the foredune notch in 2019, the end of the foredune was delineated based on following criteria. When sand and rope fences were installed, the foredune was considered from the foredune notch presented in 2019 to the restricted area marked by rope fences installed in 2020; when no rope fences were implemented, the foredune area was considered between 25 m from the foredune notch presented in 2019.

The Northern campsite extends 800 m along the beach profile, while the Southern campsite extends 1200 m, resulting in comparative analyses of values between the two campsites of 8 grid blocks and 12 grid blocks (100 m length), respectively.

Statistical analyses included the independent samples t-test to determine significant differences between the means of the Northern and Southern campsites. The test was conducted under the hypothesis that the Northern campsites' sand accumulation and height was greater than the Southern campsite, expressed as $H_a \ \mu N > \mu S$, with a confidence level of 95 %. Analyses were conducted using the jamovi project (2021) (jamovi Version 2.2.2, Computer Software, retrieved from https://www.jamovi.org).

Results

The delineation of the grid blocks (100 m in length) and foredune shape area for sand accumulation calculations are shown in Figure 3. The blocks from 1 to 8 are situated adjacent to the Northern campsite, whereas blocks 9 to 20 are located opposite the Southern campsite. Therefore, these blocks have been respectively linked to the Northern and Southern campsites for assessing the results of this analysis. There is a clear relationship between management measures applied in the Northern section of el *Cortal de la Devesa* beach and sand accumulation on the foredune. Sand fences and rope fences have led to an increase in both average height and volume, predominantly ranging from 1 m to 1.5 m in height and reaching maximum values exceeding 2 m (blocks 1 to 7 in Figure 3). The volume of sand ranges from 25 to 40 m^3 per 25 m^2.

Conversely, volumetric and altimetric increases in the Southern beach zone have not been as notable due to the absence of management measures of nature-based solutions such as sand fences and rope fences. Nevertheless, it is noteworthy that mechanical leveling and cleaning operations have ceased in the Southern sector, potentially contributing directly to dune system improvement. This factor may have resulted in height increases ranging from 40 to 60 cm in some blocks, whereas in others such as blocks 9, 15, and 16, the average height does not exceed 40 cm. The blocks with less sand increase are characterized by numerous pathways and access points from the campsite to the beach, may have influenced dune recovery.

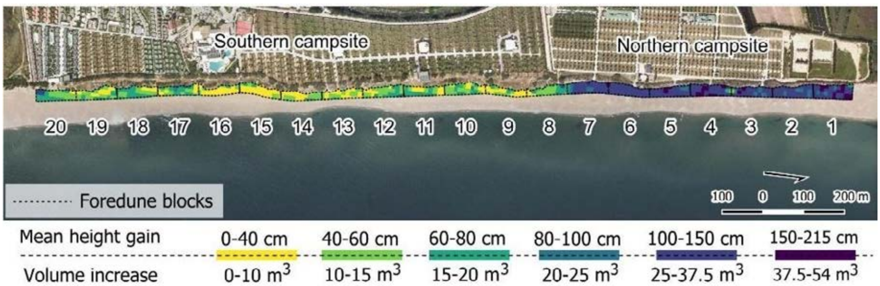

Figure 3 – Topographic changes at *el Cortal de la Devesa* beach from 2019 to 2023, detailed by the mean height gain and volume increase in the foredune, using a 5 square meter grid per cell.

Table 1 indicates averages of the development of sand dunes between the two campsites both in the years of 2019 and 2023. The Northern campsites dune profiles indicate lower average height, minimum height and volumes compared with the Southern campsite in 2019. However, in 2023, average height, maximum height and volumes increased by 60.1 %, 41 % and 60.15 %, respectively, surpassing the Southern campsite in overall values. The Southern campsite values showed modest increases in average height, maximum height and volumes, with 23.4 %, 20.4 % and 23.8 % respectively. In 2023, the Northern campsite's total volume accounted for 65.6 % of the total beach volume from sea level of the study area, while the Southern campsite's total volume made up the remaining 34.4 %.

Prior to the implementation of the sand fences in 2019, no significant differences were found between the Northern and Southern campsites in dune average height, maximum height, minimum height, and volume (Table 2). However, the Northern campsite dunes increased significantly in 2023 and were greater than the Southern campsite's dunes in all variables except for minimum height, which did not vary significantly between the Northern and Southern campsites.

Table 1 – Averages of sand accumulation between the Northern campsite (N) and the Southern campsite (S) for each grid block (Block) for average sand dune height (AH), maximum dune height (maxH), minimum height (minH) and sand dune volume (Vol) within each grid block between years 2019 and 2023. The difference in accumulation is calculated by subtracting values in 2023 by values in 2019.

		2019				2023				Difference 2019-2023			
GridBlock	Campsite	AH	maxH	minH	Vol	AH	maxH	minH	Vol	AH	maxH	minH	Vol
1	N	0.83	2.25	-0.03	2596.68	2.18	3.78	1.41	6821.64	1.35	1.53	1.44	4224.96
2	N	1.02	2.39	0.25	2762.27	2.16	3.73	1.44	5877.84	1.14	1.34	1.20	3115.57
3	N	0.81	1.94	0.31	1812.80	2.00	3.68	1.11	4523.51	1.20	1.74	0.81	2710.71
4	N	0.82	2.80	0.22	2177.11	2.11	4.09	1.13	5632.14	1.29	1.29	0.91	3455.03
5	N	0.73	1.56	0.24	1714.31	2.04	3.47	1.34	4808.27	1.31	1.91	1.11	3093.96
6	N	0.75	2.17	0.23	1892.12	2.05	3.62	1.27	5169.62	1.30	1.45	1.04	3277.49
7	N	0.87	1.83	0.25	2380.00	2.02	3.17	1.43	5574.01	1.16	1.34	1.17	3194.02
8	N	1.72	3.35	0.85	3451.91	2.31	3.88	1.43	4645.11	0.59	0.53	0.58	1193.19
9	S	1.61	3.11	1.08	3000.95	1.95	3.25	1.31	3647.07	0.34	0.14	0.24	646.12
10	S	1.56	2.58	0.91	3920.41	2.07	3.41	1.44	5217.22	0.51	0.83	0.53	1296.81
11	S	1.37	2.69	0.65	3090.08	1.90	3.21	1.11	4297.83	0.53	0.51	0.46	1207.75
12	S	1.47	2.63	0.77	3618.59	1.98	3.25	0.55	4878.07	0.51	0.62	-0.22	1259.49
13	S	1.54	2.76	0.93	3215.27	1.94	3.37	1.16	4059.13	0.40	0.61	0.23	843.86
14	S	1.49	2.47	0.91	2817.92	1.84	2.91	1.30	3490.38	0.35	0.44	0.39	672.46
15	S	1.63	2.58	1.00	3916.71	1.95	3.11	1.42	4706.87	0.32	0.54	0.42	790.16
16	S	1.68	2.91	1.14	3383.37	1.96	3.17	1.34	3959.68	0.28	0.26	0.19	576.31
17	S	1.50	2.45	0.95	3361.97	2.05	3.46	1.50	4607.35	0.55	1.01	0.55	1245.38
18	S	1.51	2.75	0.95	3726.57	2.08	3.35	1.63	5147.27	0.57	0.60	0.68	1420.70
19	S	1.52	2.09	0.99	3886.71	1.97	3.08	1.13	5046.28	0.45	0.99	0.14	1159.57
20	S	1.25	1.67	0.82	3061.27	1.89	3.35	1.55	4660.28	0.65	1.67	0.74	1599.01
TOTAL	N	0.9	2.3	0.3	2348.4	2.1	3.7	1.3	5381.5	1.2	1.4	1.0	24264.94
TOTAL	S	1.5	2.6	0.9	3416.7	2.0	3.2	1.3	4476.5	0.5	0.7	0.4	12717.61

Table 2 – Independent samples t-test to determine significant difference between the means of the Northern and Southern campsites for average height (AH), maximum height (maxH), minimum height (minH) and volume (Vol). The test was conducted under the hypothesis that the Northern campsites' sand accumulation and height was greater than the Southern campsite, expressed as: $H_a\ \mu N > \mu S$ with significance of $p < 0.05$ indicated with asterisks.

2019				**2023**			
Variable	**Statistic**	**df**	**p**	**Variable**	**Statistic**	**df**	**p**
AH	-12.84	18	1	AH	1.84	18	0.04*
maxH	-2.48	18	0.98	maxH	3.01	18	0.004*
minH	-12.32	18	1	minH	0.05	18	0.48
Vol	-6.82	18	1	Vol	3.36	18	0.002*

Discussion

Before the implementation of nature-based solutions and the installation of the sand fences, both the Northern and Southern campsite beaches had similar sand dune morphologies, with the Southern campsites' average height and minimum height significantly higher than the Northern campsites' (data not shown here). Although the reasons for this fall outside the scope of this study, the installation of the fences in 2020 appeared to have an influence in the increase in sand accumulation in both areas, which is evident in the increases in the Southern campsite by 2023. However, with the management of dune restoration ceasing in the Southern campsite's beach area in 2021, the accumulation slowed, with the Northern campsite´s sand accumulation surpassing the Southern campsite by 2023, accounting for over 60 % of the total sand volume for the entire study reach. Previous studies found that the main causes of dune degradation in Spain included, amongst others, massive tourist development and that once mitigated or controlled, "soft" techniques such as sand trapping and dune fencing were effective in reducing dune degradation [6]. The significant changes experienced over a short time span between the two campsite areas indicate the effectiveness of these implementations and highlight the importance of managing these areas after installation. Without regulating beach access and limiting mechanical cleaning, the effectiveness is somewhat negated, with slower progression in dune recovery and more susceptibility to other occurrences, such as invasive plant succession [7] and [8]. Given the destructive-formative cycles that occur annually, vegetation stabilization is crucial in reinforcing the first stage of dune succession created by sand trapping and is linked to access control and fencing. The rate of sand accumulation over a 4-year period also indicates the potential for recovery, given the right conditions.

Furthermore, the use of UAVs in this study has provided empirical data for comparison between two distinctly managed areas and has provided insights into coastal dune dynamics under strategies that are often difficult to quantify, given the qualitative nature associated with the implementation and enforcement of such strategies. Highly accurate coastal monitoring is challenging at best, given the complexity of coastal landforms [9]. Only by accurately mapping the changes over time of sand dune dynamics and growth can assessments of management be accurate and objective. In the same study area, [10] examined the historical evolution of beach-dune systems over the past five decades and identified a clear relationship between sustainable management measures or nature-based solutions and the recovery of the dune system over time. However, they did not employ empirical methods capable of quantifying dune recovery, relying instead on a more qualitative approach compared to the quantitative methods utilized in this study.

Interestingly, comparable results were observed at the *La Pletera* beach, located in Costa Brava, NE Spain [11]. Notably, the primary height of the foredune increased from 1.6 m to 2.7 m between 2017 and 2018 following the installation of sand fences. This mirrors the elevation change observed at the northern part of *El Cortal de la Devesa* beach (Table 1), which showed an increase from 0.9 m to 2.1 m, marking the most significant findings in our study. The average increase at La Pletera beach was comparatively higher (68 %) than the increase observed at the northern part of *El Cortal de la Devesa* beach (60.1 %). This difference can be attributed to La Pletera beach's initially lower elevation above sea level and the limited one-year duration of the current study. This study at la Pletera suggests that the implementation of management measures is unequivocally the key factor in dune recovery regarding morphology. In fact, the unmanaged areas of our study, such as the Southern campsite, have not achieved comparable figures to those attained at la Pletera beach or the northern sector of *el Cortal de la Devesa* beach, failing to even reach a 25% increase in average height, rising from 1.5 m to 2 m in average elevation.

Most field and wind tunnel studies suggest that sand-trapping fences with porosities around 40 % to 50 % are most effective in capturing sand drift [12]. Fences that are too dense can alter wind direction, whereas overly porous ones have a limited impact on airflow, resulting in minimal sand deposition. In contrast to established recommendations, studies along the Costa Brava employed fences with porosities ranging from 50 % to 60 %, yielding positive outcomes. Similarly, research conducted in Taiwan [13] achieved favorable results with a porosity of 66%, challenging prevailing guidelines found in reviews and manuals. Given the unique dynamics and complexities of each beach environment, it is prudent to conduct rigorous tests and trials specific to the site before installing sand fences. This assessment should include a thorough examination of factors such as porosity, height, and fence density to optimize the effectiveness of the restoration strategy.

Conclusion

As tourism-driven dune degradation increases, so too does the need for integrated conservation strategies by combining nature-based solutions with management strategies, to restore and protect these important ecosystems. The use of UAVs in this study has quantified changes in sediment retention and dune height of the foredune area of both campsite areas between 2019 and 2023 and has provided a unique comparison of inherently similar morphologies and climatic conditions, but with different management strategies. Despite the initial increase in sand accumulation in the foredunes of both areas, the Northern campsite surpassed the Southern campsite by 2023 in volume, maximum height, and average height. This is attributed to the discontinued management of people access and mechanical cleaning of the foredune area in 2021 in the Southern campsite. Also, an 85 % efficacy in trapping sand was noted with a sand fence porosity of 50÷60 %. Through empirical evidence, this study has highlighted the potential of tourist-recreational sites in bolstering climate change resilience along coastlines. Implementing management strategies with nature-based solutions could improve beach-dune profiles, thus safeguarding coastal users and facilities from the impacts of climate change.

Acknowledgements

This research has been carried out within the framework of the IMPETUS project (ref. 101037084) funded by the European Commission granted under the call of the Horizon 2020 and within the framework of the CoastSpace project (ref. TED2021-130001B-C22) funded by MCIN/AEI/10.13039/501100011033 and by the "European Union NextGenerationEU/PRTR".

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THE ESA ULYSSES PROJECT AND THE EXPLOITATION IN THE MEDITERRANEAN AREA OF SOIL SEALING PRODUCTS AND INDICATORS

Daniela Iasillo, Vito De Pasquale, Paola Di Lauro, Sadri Haouet, Amaury Truffier, Loïc Faucqueur, Luca Congedo, Michele Munafò, Olivier Arino

Abstract: Soil sealing, a phenomenon altering soil permeability, significantly impacts the environment, particularly in urban areas and local climates, affecting heat exchange and soil permeability. Monitoring soil sealing is crucial for the Mediterranean coastal regions, where it contributes to desertification alongside soil degradation, drought, and fires.

Permanent soil sealing includes features like buildings and paved roads, while reversible sealing involves features like solar panels and early-stage construction sites. The Mediterranean Soil Sealing project, led by Planetek Italia with partners ISPRA and CLS, aims to provide high-resolution maps of soil sealing and reversible sealing from 2018 to 2022, with a spatial resolution of 10m.

The project emphasizes stakeholder involvement, with users ranging from municipalities to international organizations like the UN. Efforts have been made to engage diverse stakeholders from the project's outset, and stakeholders are actively involved in shaping project outcomes. Instead of simply delivering maps, the project will provide users with an interactive dashboard containing indicators and analytics for easy access to information.

Keywords: sealing, imperviousness, coastal areas, mediterranean.

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Daniela Iasillo, Vito De Pasquale, Paola Di Lauro, Sadri Haouet, Amaury Truffier, Loïc Faucqueur, Luca Congedo, Michele Munafò, Olivier Arino, *The ESA Ulysses project and the exploitation in the Mediterranean area of Soil Sealing products and indicators*, pp. 741-749, DOI: 10.36253/979-12-215-0556-6.64

Introduction

Soil sealing is a process resulting from human activities that alter the soil's permeability due to the use of artificial materials and compaction. The environmental consequences of soil sealing, also known as imperviousness, are numerous. It affects urban areas and local climates, impacting heat exchange, soil permeability, water infiltration, groundwater recharge, and more [3, 7, 8, 9].

At the European level, the recent proposal for a Directive of the European Parliament and the Council on Soil Monitoring and Resilience underscores the need to monitor land take, soil sealing, and the associated impacts on ecosystem services [3].

The European EAGLE classification system, developed by the EIONET EAGLE group "Action Group on Land Monitoring in Europe," categorizes soil sealing under class 1.1.1, "Sealed Artificial Surfaces and Constructions." This category includes surfaces covered with artificial structures, such as buildings, pavements, and other impervious surfaces [2].

The United Nations has also highlighted the importance of monitoring coastline imperviousness in the United Nations Environment Programme – Mediterranean Action Plan (IMAP) due to its impact on soil weathering properties and aeolian transport patterns [10].

This paper introduces a new service developed for the Mediterranean Soil Sealing project, promoted by the European Space Agency under the EO Science for Society – Mediterranean Regional Initiative. The project, named Ulysses (https://www.ulysses-project.org), aims to develop a methodology for monitoring the degree of soil sealing using Copernicus Sentinel images over Mediterranean coastal areas (within 20 km from the coast) at a spatial resolution of 10 meters (Figure 1). Currently, the service is available for the reference year 2020, and additional reference years from 2018 to 2022 will be produced by the end of the project.

Furthermore, the project aims to provide end-users with various indicators and statistics derived from the maps, offering information that can be directly integrated into their workflows.

Figure 1 – The 2020 Soil Sealing Degree Map for Mediterranean coastal regions (within 20 km from the coastline) is based on cloud-free Sentinel-2 imagery.

Materials and Methods

The project mandates the utilization of Sentinel-2 imagery, with a spatial resolution of 10 meters, to gauge soil sealing. The selection of appropriate algorithms depends on the availability of auxiliary data and the need to accurately estimate soil sealing percentages. At this scale (i.e., a pixel area of 100 m²), it is crucial to detect variations in soil sealing down to 1 m² of impervious surface.

Moreover, leveraging Sentinel-2 satellite data (comprising visible and near-infrared bands) requires analyzing land cover attributes at a subpixel level. This involves addressing the challenge of mixed pixels (which contain multiple land cover classes within a single pixel) and accounting for the spectral similarity between natural soil and artificial surfaces.

To overcome these challenges, a multifaceted methodology was devised (see Figure 2). First, Sentinel-2 Level 1C input data undergoes correction to Level 2A via the MAJA processor, while the Normalized Difference Vegetation Index (NDVI) is calculated for each image for a baseline year. Next, Level 3A cloud-free composites are generated for each month from the Level 2A data. These composites include the calculation of various indices, such as NDVI, Normalized Difference Tillage Index (NDTI), Modified Normalized Difference Water Index (MNDWI), Normalized Difference Built-up Index (NDBI), and a PANTEX band, which serves as a texture descriptor particularly useful for urban area depiction [6].

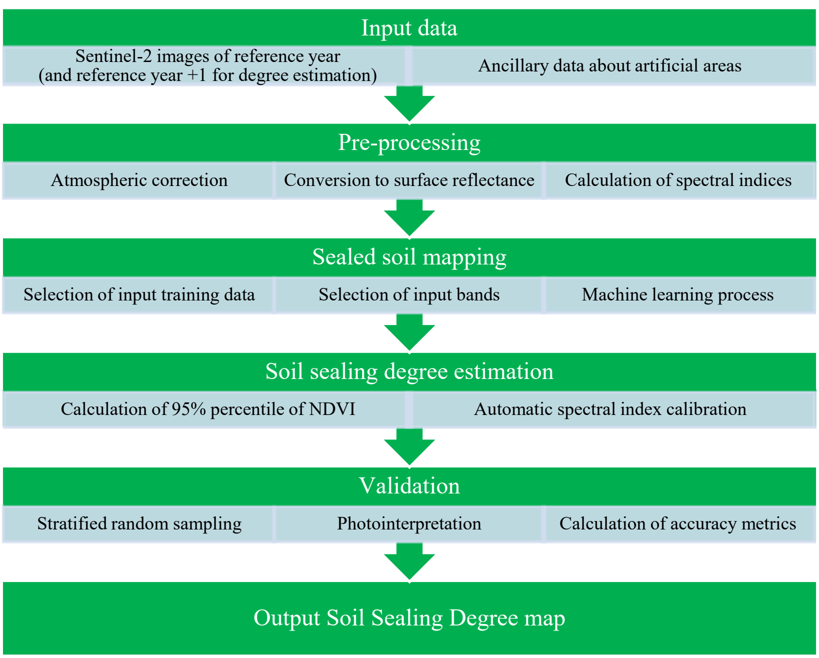

Figure 2 – Workflow of the processing chain.

Mapping of sealed terrain is carried out using machine learning techniques applied to Sentinel-2 imagery, via a tool called "Broceliande." This involves selecting bands and constructing a morphological tree model, from which multiscale characteristics (referred to as attribute profiles) are derived [1, 5]. Specific attributes (e.g., area, weight, compactness) are measured for all objects at varying scales within each hierarchical representation, and these attributes are assigned to each pixel. A binary classification process (sealed/unsealed) is then performed using a Random Forest classifier.

The estimation of soil sealing degree is carried out on the sealed soil mask generated in the previous step. A significant challenge in computing soil sealing degree is the lack of very high-resolution reference data (i.e., at least 1m resolution) that could be used as training data. To address this, an automatic approach was developed to eliminate the need for training data, particularly given the large study area (i.e., the Mediterranean basin).

Specifically, the NDVI time series calculated for each Sentinel-2 image is used to extract the 95th percentile of NDVI over the reference year and the following year. Using two years of images helps reduce NDVI fluctuations due to the seasonality of vegetation in mixed pixels and allows for the detection of changes that cause a permanent decrease in NDVI, such as new constructions. Spectral index calibration, which does not require training data, is then performed to estimate soil sealing degree at the pixel level [4]. This method automatically estimates the minimum and maximum values of the spectral index (i.e., the 95th percentile of NDVI) to calibrate a linear relationship with soil sealing degree.

The result of this entire process is a raster map with 10 m spatial resolution, where each pixel represents the soil sealing degree (ranging from 0 to 100 %) within 20 km from the coastline (Figure 3).

Validation was performed at two levels of analysis using stratified random sampling:

- Thematic validation to estimate both producer and user accuracies for the sealed areas.
- Correlation analysis with soil sealing degree to assess the reliability of the degree values.

The thematic validation of the sealed soil mask achieved an overall accuracy of 96 %, with a user's accuracy of 85.9 % (indicating low commission errors) and a producer's accuracy of 64.1 % (indicating high omission errors due to difficulties in identifying small sealed features, such as narrow roads, small and isolated buildings, and partly due to the different resolution between the product and validation reference data). Most omission errors are located in areas where the soil sealing degree is less than 30 %.

The correlation analysis of the soil sealing degree showed a significant correlation, with a coefficient of determination equal to 0.7. Additionally, the absolute difference between the product's soil sealing degree and the sample's sealing degree was less than 30 for 80 % of the samples, confirming substantial agreement, especially for higher levels of soil sealing.

Figure 3 – Example of soil sealing degree (right) compared to very high-resolution image (Google Earth, right image); different level of urban density is represented by higher values of imperviousness over compact areas, and lower values of imperviousness are present over dispersed buildings mixed with vegetation.

Results

The monitoring service is currently available, and the data can be freely accessed on the project website. Ulysses offers a comprehensive mapping tool that facilitates the use of soil sealing products by visualizing and analyzing critical soil sealing indicators through a user-friendly web application. This tool allows users to access and interpret data at both country and regional levels. These two administrative levels are represented in two different web applications (available on the project website).

The two applications contain different indicators: the country-level map offers an overview of the product series and a first global analysis (the soil sealing consumption in the countries within the AOI), while the regional-level web app provides a series of four different indicators. These indicators represent a set of geospatial data, in the form of percentage values, offering insights into the distribution of soil sealing within the area of interest. These data are derived from the output products (for the 5 years of analysis), representing the percentage of sealing in each pixel of the area of interest, with values ranging from 0 to 100.

Each indicator offers a specific analysis of sealing distribution in the studied area. The four metrics include the percentage of soil sealing within:

- the administrative boundaries (referred to the 20 km buffer from the coast);
- the 2000 m buffer zone from the coastline;
- the 1000 m buffer zone from the coastline;
- the 500 m buffer zone from the coastline.

The soil sealing indicators have been derived by considering the percentage value of each pixel. For instance, assume that within the area bounded by one of the indicators (i.e., an area up to 500 m, 1 km, 2 km, or 20 km from the coast) there are 20 pixels with a 50 % sealing percentage. The calculation is performed as follows:

$$20 \text{ [count of pixels]} \times 100 \text{ [m}^2\text{]} \times 50\%$$

This quantity, relative to the area's extent, provides the value of the indicator. Thus, if the considered polygon has an area of 10 000 m², we'll have 10 % sealing within that polygon.

In summary, the methodology for calculating the indicators involves the following steps:

- Pixel Value Consideration: Each pixel's value in the GeoTIFF represents the percentage of sealing within that specific area.
- Pixel Count: This step involves counting the pixels inside the administrative polygon.
- Conversion to Meters: The percentage value of each pixel is multiplied by the area occupied by each pixel. This value depends on the raster output resolution; in the case of Sentinel-2 datasets, this is 10 × 10 = 100 m².
- Aggregation and Normalization: The product of the pixel count and the relative area is normalized by the total area of the administrative polygon to obtain the sealing percentage.

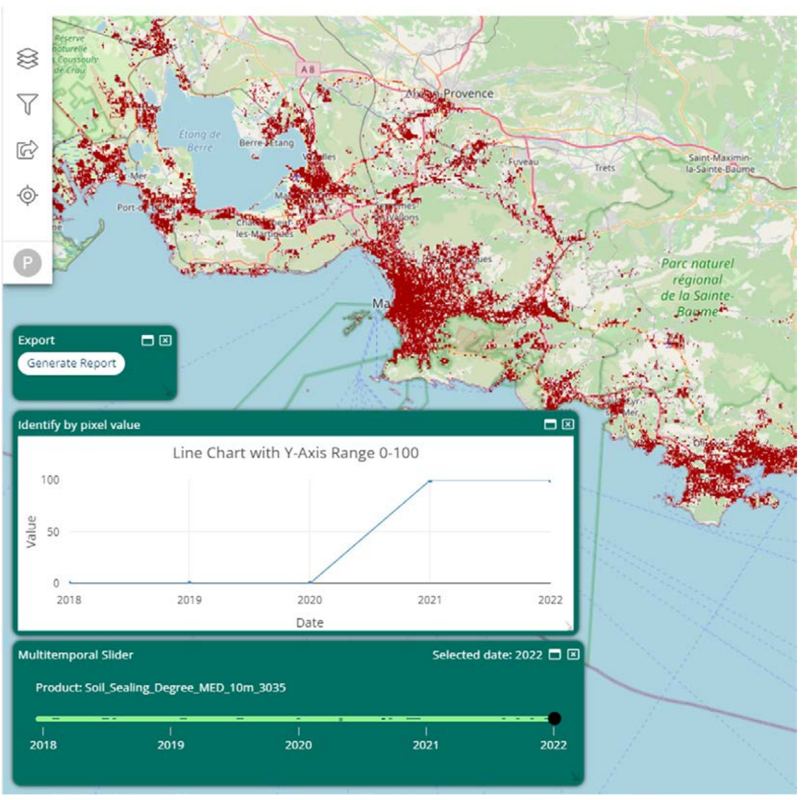

Figure 4 – Example of soil sealing trend from regional web app.

This procedure has been repeated four times for each of the four sealing indicators across five years of data, resulting in a total of 20 indicators, which can be visualized on a map as a time series. This time series visualization allows users to track the trend of sealing in a specific region over time.

These indicators, computed annually from 2018 to 2022, allow for temporal analysis of soil sealing trends across the different administrative levels. Figures 4 and 5 depict the web application interface.

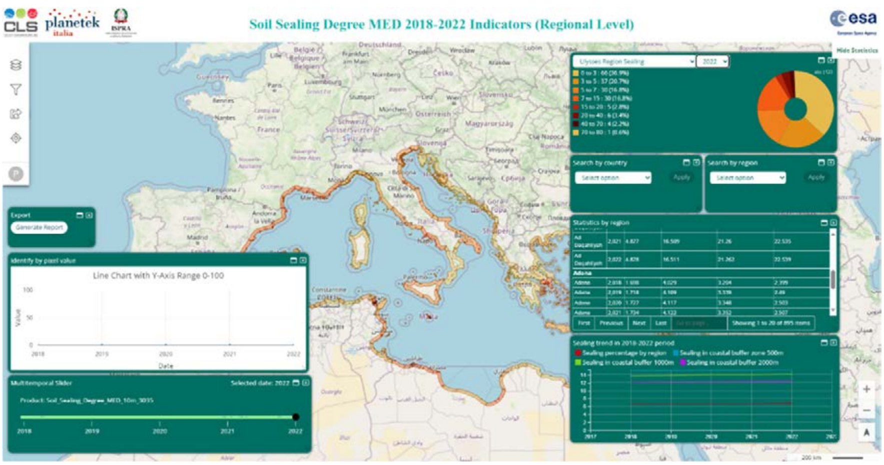

Figure 5 – Main features and analytics from regional web app.

Discussion and conclusion

The monitoring of soil sealing is of paramount importance due to its profound ramifications on human health, environmental quality, and the provision of ecosystem services. This study introduces a novel service tailored for monitoring soil sealing degrees, developed within the framework of the Mediterranean Soil Sealing project. The primary objective of this service is to furnish comprehensive insights into soil sealing dynamics across the entire Mediterranean coast. Leveraging Copernicus Sentinel-2 imagery, the methodology enables annual updates of soil sealing maps spanning from 2018 to 2022, with a spatial resolution of 10 meters. The thematic accuracy is achieved through a detailed methodology that includes pre-processing of satellite imagery (e.g., atmospheric correction and calculation of spectral indices such as NDVI), machine learning classification, and spectral index calibration without the need for high-resolution training data.

Beyond the provision of maps, the Ulysses web application enhances accessibility to soil sealing information and its temporal changes. It offers a suite of indicators correlating soil sealing with pertinent environmental parameters, such as proximity to protected areas and rivers. The platform is designed to be user-friendly, allowing easy access to critical data for a range of users, including those with limited technical expertise. The inclusion of visualizations at both the national and regional levels further enhances usability for stakeholders and urban planners, ensuring the dashboard remains accessible to users without advanced GIS or remote sensing skills.

To ensure that the project remains collaborative and responsive to stakeholder needs, regular communication and feedback mechanisms have been incorporated from the outset. Engaging municipalities, international organizations, and other stakeholders has been key to shaping the project's outcomes, with feedback being actively used to refine the interactive tools provided by the Ulysses web application. This participatory approach ensures that stakeholders are fully involved in the decision-making process and that the tools developed align with their requirements.

The maps and indicators presented in this study hold promise for fostering sustainable development within collaborative initiatives across the Mediterranean region. They align with directives set forth by the United Nations Environment Programme and contribute to broader efforts, such as the Priority Actions Programme/Regional Activity Centre under the Mediterranean Action Plan. Additionally, they offer valuable data for key indicators such as Candidate Common Indicator 25, "Land Use Change," affiliated with Ecological Objective 8 (Coastal Ecosystems and Landscapes). Metrics like the extent of impervious surfaces within a 100-meter buffer from the coastline can inform evidence-based decision-making processes, ultimately guiding sustainable management of coastal environments across the Mediterranean.

Acknowledgment

This work is part of the ESA Ulysses project focused on Mediterranean Soil Sealing, supported by the European Space Agency (ESA) under the EO Science for Society – Mediterranean Regional Initiative, Land applications. More information is available at https://www.ulysses-project.org/.

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MODELLING OF WAVE HEIGHT, CURRENTS AND SEDIMENT TRANSPORT AT LOCOS BEACH (TORREVIEJA, SPAIN) BEFORE AND AFTER NOURISHMENT

Isabel López, José I. Pagán

Abstract: The paper studies the impact of a coarse sand nourishment project at Locos beach in Torrevieja, Spain, in January 2020, on coastal dynamics. The objective is to model the changes in wave heights, currents, and potential sediment transport due to the nourishment. The SMC 2.5 software was employed to simulate the beach evolution. The results show that the nourishment caused a reduction in wave height in some directions, especially in the ENE direction, and a decrease in current velocity in all directions. The potential sediment transport was reduced by three times in all directions after nourishment, and in the northern part, it almost disappeared. Nourishment also decreased the number and intensity of eddies in the surf zone, implying a decrease in rip currents, and enhancing safety for beachgoers. Additionally, nourishment led to a reduction in potential sediment transport, improving the stability of the cross-shore beach profile against storms. The findings suggest that coarse sand nourishment at Locos beach has positively impacted both stability and safety, providing valuable insights for future coastal beach management and design.

Keywords: Sediment transport, Coastal morphodynamics, Erosion, Beach nourishment

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Isabel López, José I. Pagán, *Modelling of wave height, currents and sediment transport at Locos beach (Torrevieja, Spain) before and after nourishment*, pp. 750-760, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.65

Introduction

The dumping of sand on beaches to combat coastal erosion is a common process [2]. In recent years, due to a scarcity of natural material (fine sand), nourishment has been performed with coarse sand from quarries. Altering the characteristics of a beach or coastline, such as the dumping of material different from the existing one, can destabilize the local coastal dynamics [7]. Modification of beach morphology includes modifications of beach topography, shoreline position and nearshore bathymetry due to natural or anthropogenic factors [8]. The modification of the nearshore bathymetry leads to a series of adjustment dynamics that produce sediment movement [6]. Additionally, hydrodynamic forces, including sea waves, tides, and wave currents, contribute to morphological changes within coastal environments.

For modelling ocean waves and currents, advanced computational and simulation tools are used. The Coupled Ocean-Atmosphere-Wave-Sediment Transport Modelling System (COAWST) is an example of a complex model that integrates different components, such as the Regional Ocean Modelling System (ROMS) to solve the three-dimensional Reynolds-averaged Navier-Stokes (RANS) equations, the WRF atmospheric model, the SWAN wave model, and the Community Sediment Transport Modelling System (CSTMS) to model sediment transport [10]. The 2DH mathematical model, built on the Delft3D platform, is another example of a modelling tool that includes external forcings due to tidal, wave, and atmospheric forcing [9]. Finally, Coastal Modelling System (CMS) is another example of a modelling tool designed for critical coastal zone solutions, wave characterization, flood elevation determination and bathymetric information [3].

Therefore, because of the importance of investigating the modifications that the wave heights, currents and sediment transport of an area will undergo due to beach nourishment, the objective of this work is to model the wave heights, currents, and sediment transport before and after the nourishment of a beach with coarser material than the original one.

Study area

The study area (Figure 1) is located at Locos beach (Torrevieja, Spain) and is characterized by a temperate Mediterranean climate, with a semi-warm subtropical sea temperature regime averaging 20.5 °C. The local wave regime is significantly influenced by seasonal variations. The 470-meter-long beach is sheltered from northeast swells by the "Punta del Salaret" cape, while an artificial breakwater provides southern protection. The beach experiences moderate wave conditions, with a mean significant wave height of 0.64 m and a mean period of 3.7 s.

A small rocky step induces undertow currents, leading to sand loss that cannot be replenished due to the specific bathymetric conditions. Originally a sandy beach with a median sediment size of 0.193 mm, the beach underwent nourishment in January 2020 using quarry material with a median sediment size of 1.19 mm. The material was dumped along the entire width of the beach, placing the material both on the backshore and on the shoreface of the beach, increasing the beach width by an average of 10 m (Figure 2).

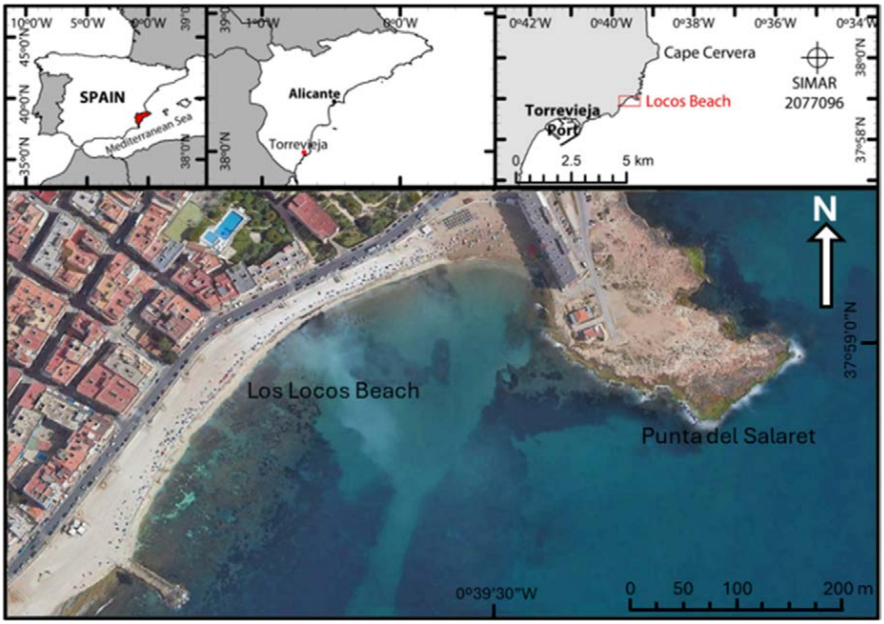

Figure 1 – a) Locos beach located in Torrevieja (province of Alicante, Spain) and with the location of the SIMAR node used for wave data.

Figure 2 – a) Locos beach pre-nourishment. b) Locos beach during nourishment. C) Locos beach near post-nourishment.

Materials and Methods

Modelling of wave height, currents and potential sediment transport was carried out at Locos beach for pre and post-nourishment modelling, bathymetry and wave data were necessary.

The pre-nourishment bathymetry was obtained from the Eco-cartography of Alicante obtained with Multibeam sounder at 1:1000 scale (www.miteco.gob.es/es/costas/temas/proteccion-costa/ecocartografias/ecocartografia-alicante.html). Post-nourishment bathymetry was obtained at the end of October 2023 using a single beam unmanned surface vessel (APACHE 3) developed by CHCNAV (www.chcnav.com).

The swell data were obtained from the SIMAR node 2077096 provided by Puertos del Estado (www.puertos.es). The SIMAR data is an hourly record of wave height, swell period, and direction from 1958 to the present. These data were processed to obtain for each direction incident on the beach the wave heights $H_{s,12}$ (exceedance probability of 0.137 %) and their corresponding periods. In addition, to model the behaviour of the beach cross-shore profiles against storms, storms from 1958 to November 2023 were analysed. A storm was considered an event with a height equal to or greater than the 95th percentile and a minimum duration of 6 hours.

Finally, the beach modelling was performed with the SMC 2.5 software (Coastal Modelling System, http://www.smc.unican.es) of the Environmental Hydraulics Institute of the University of Cantabria. SMC consists of five modules (preprocessing module; short-term module; long-term module; bathymetry module; and tutorial module). In this work, the short-term module was used to analyse short-term coastal systems (hours-days). It is composed of a model of morphodynamic evolution of the beach profile (PETRA) and plant (MOPLA) that allows obtaining, among others: wave height, currents, and potential sediment transport.

Results

First, the swell results obtained in the study area are shown. The beach is affected by waves coming from N78ºE to N184ºE (Figure 3a). As can be seen, the highest wave heights are those coming from the E, being also the highest heights those with the longest period (Figure 3b), thus the highest wave height reached was 4.99 m with a period of 9.7 s. In addition, the wave height decreases towards the south.

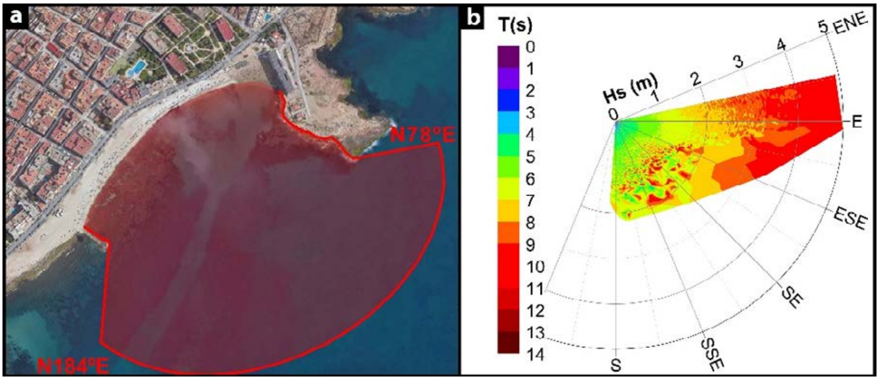

Figure 3 – a) Incident wave sectors on the beach. b) Wave height and period by directions.

Next, different wave heights were obtained for each of the incident directions on the beach, including wave heights $H_{s,12}$ and their corresponding period. Table 1 shows that the most frequent direction on the beach is E (52.31 %) with a wave height $H_{s,12}$ of 3.37 m and a period of 8.9, the direction with the highest wave height $H_{s,12}$ (3.54 m) is ENE, but it only occurs 1.83 % of the time. On the other hand, the direction from the south stands out, although it has the lowest height (1.53 m), reaching 13.23 % of the time.

Table 1 – Probability of occurrence (frequency), median wave height ($H_{50\%}$), wave height exceeded 10% of the time ($H_{90\%}$), maximum wave height (H_{max}) and the wave height $H_{s,12}$ with its corresponding period for each of the incident directions on the beach.

Direction	Frecuency	$H_{50\%}$ (m)	$H_{90\%}$ (m)	H_{max} (m)	$H_{s,12}$ (m)	T (s)
ENE (N78ºE-N78.75ºE)	1.83%	0.71	1.47	4.92	3.54	9.86
E (N78.75ºE-N101.25ºE)	52.31%	0.66	1.35	4.99	3.37	8.87
ESE (N101.25ºE-N123.75ºE)	19.29%	0.49	0.95	3.53	1.84	7.11
SE (N123.75ºE-N146.25ºE)	6.18%	0.37	0.68	2.39	1.86	7.25
SSE (N146.25ºE-N168.75ºE)	7.16%	0.37	0.70	2.18	1.63	6.69
S (N168.75ºE-N184ºE)	13.23%	0.41	0.75	2.19	1.53	6.41

To conclude the wave analysis, storms were studied (Figure 4). For this beach, a storm was considered when the wave height was greater than 1.45 m (95th percentile of the swell on the beach). With these conditions from 1958 to the end of October 2023, there were 860 storms. The average on the beach is 13 storms/year with an average duration of 32.6 hours and an average height of 1.79 m. The maximum storm occurred in 2020 with an average height of 2.74 m and a duration of 108 hours but barely affected the beach (Figure 4c).

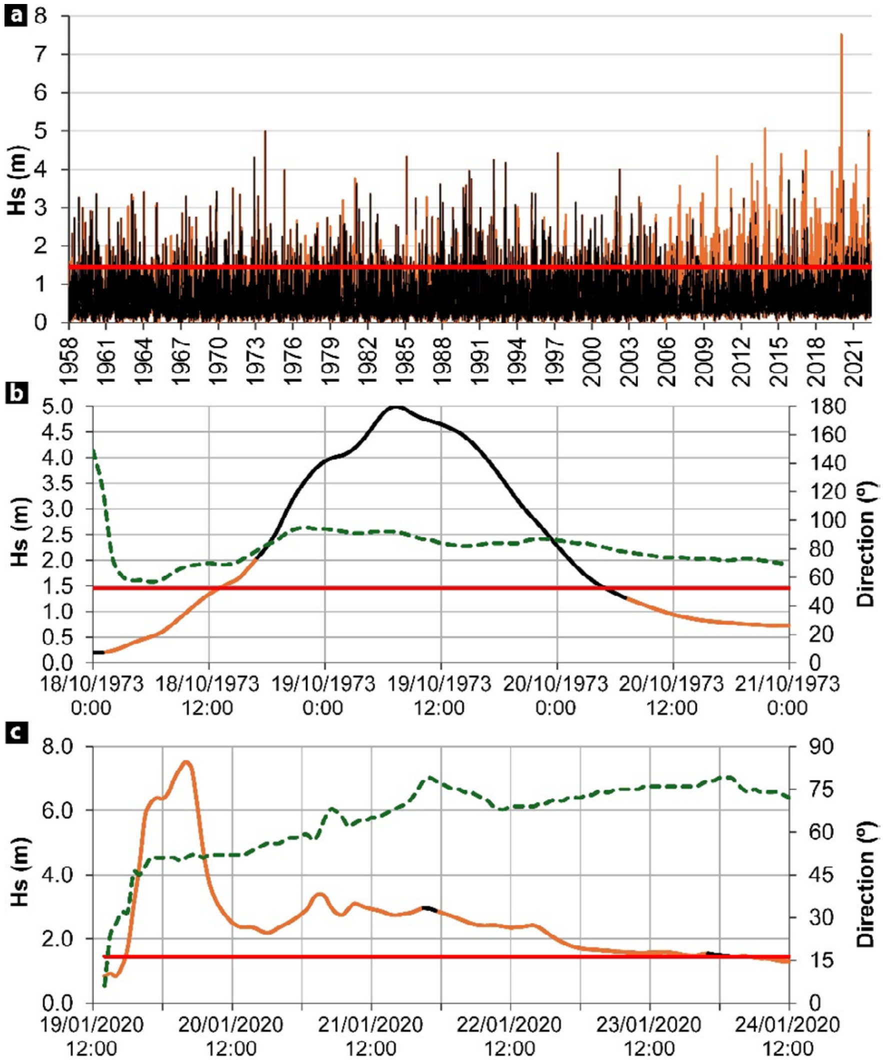

Figure 4 – a) Waves and storms in the study area. b) Major storm that affected the beach. c) Major storm in the study area. The horizontal red line shows the wave height limit for a storm (1.45 m), the orange line shows all waves, the black line shows only the incident waves on the beach, and the dashed green line indicates the direction of the waves.

Regarding the wave modelling, Figure 5 shows the wave heights and currents produced on the beach before and after nourishment, only three of the six incident directions are shown due to their higher relevance. The variation in wave height is minimal (less than 0.1 m) except for the ENE direction, where it decreases by 0.7 m (Table 2). The currents exhibit greater variability than the wave height, with a decrease in velocity across all directions, particularly in the flow direction. For instance, for the ENE direction before nourishment, two eddies were formed, one in the central zone and a smaller one in the southern zone, while after nourishment there is only one eddy more towards the south and of lower intensity. Something similar occurs in the other directions where in all cases the southern eddy disappears and the eddies to the north modify their location and generally decrease their intensity.

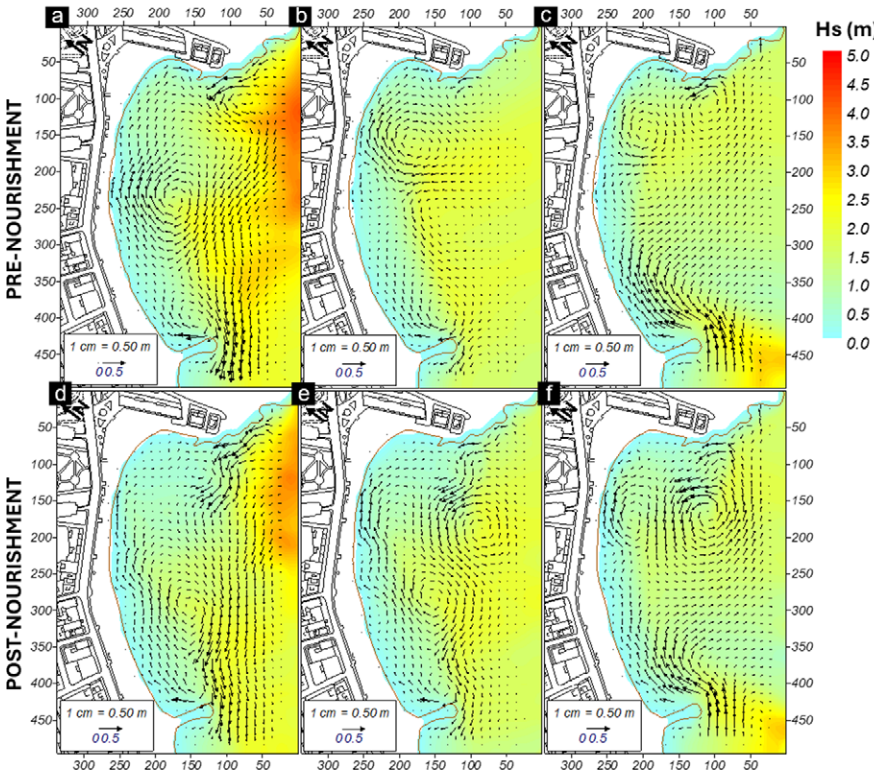

Figure 5 – Wave height and currents for swell coming from: a) ENE; b) ESE; c) SSE; d) ENE; e) ESE; f) SSE.

From the modelling of the potential sediment transport, it is apparent that after the beach nourishment, it is divided by three in all directions (Table 2). It is also observed that in the northern part of the beach sediment transport practically disappears (Figure 6), being the most probable transport in the central and southern part in a mainly north-south direction.

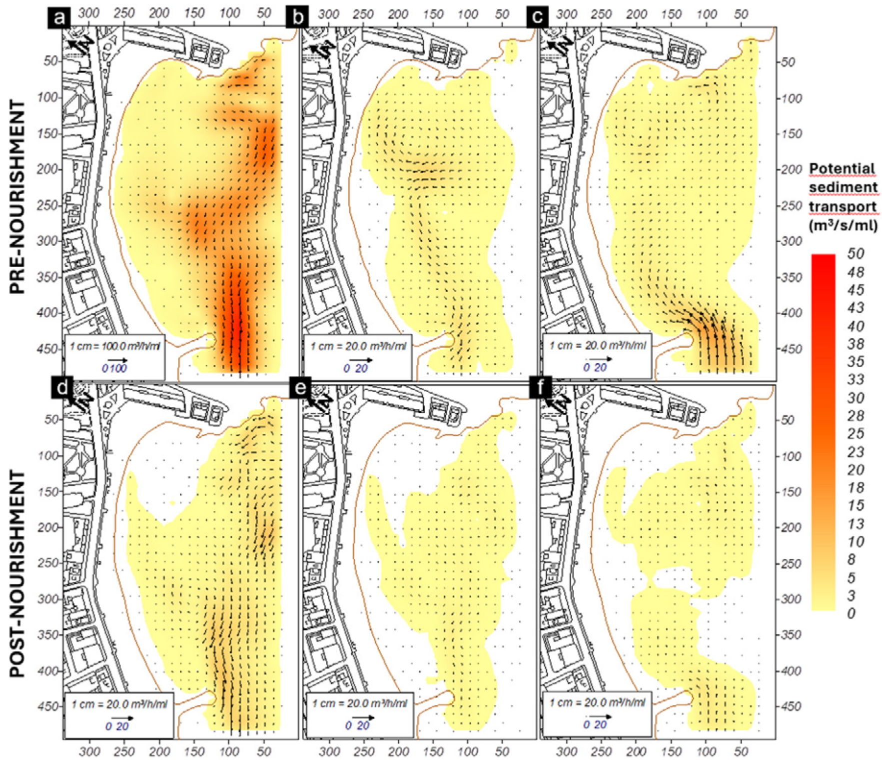

Figure 6 – Potential sediment transport for swell coming from: a) ENE; b) ESE; c) SSE; d) ENE; e) ESE; f) SSE.

Table 2 – Maximum values of wave height, current velocity, and potential sediment transport for each direction before and after beach nourishment.

		Wave direction					
		ENE	E	ESE	SE	SSE	S
Wave height (m)	Pre-Nourishment	2.8	1.9	2.1	2.1	1.7	2.2
	Post-Nourishment	2.1	1.9	2.0	2.1	1.7	2.2
Currents (m/s)	Pre-Nourishment	0.51	0.65	0.63	0.53	0.87	0.76
	Post-Nourishment	0.58	0.51	0.54	0.50	0.82	0.72
Potential transport (m^3/s/ml)	Pre-Nourishment	43.1	10.8	6.5	6.8	15.9	9.5
	Post-Nourishment	11.8	3.7	2.6	3.4	4.2	3.5

Finally, the evolution of the cross-shore beach profile against a mean storm coming from the east is studied (Figure 7). This storm has a duration of 72 h, starts with a wave height of 0.88 m, reaches the maximum value of wave height (2.05 m) at 30 h, and ends at 72 h with a wave height of 0.67 m (Figure 7a). The analysis shows that the pre-nourishment profile would undergo a shoreline retreat of 7.4 m (Figure 7c), while the post-nourishment profile would only retreat 3.3 m (Figure 7d). In both cases, the profile variations cease at depths of 4 m.

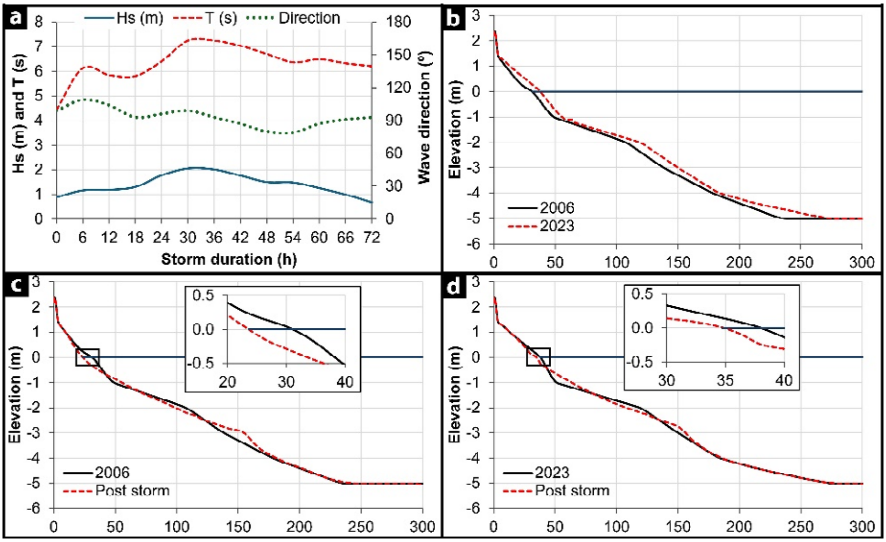

Figure 7 – Effect of storms on the cross-shore profile. a) Characterization of the storm. b) Comparison of the 2006 profile with the 2023 profile. c) Evolution of the 2006 profile during the storm. d) Evolution of the 2023 profile during the storm.

Discussion

Coastal design and management require an important understanding of coastal dynamics. Numerical models are valuable tools for comprehending and predicting the impacts of storms and sea level changes on coastal dynamics [5]. Therefore, this study focuses on modelling wave height, currents, potential sediment transport, and the evolution of the cross-shore profile of Locos Beach both before and after nourishment.

The results show that sand nourishment with coarser than existing sand (D_{50} = 1.2 mm *vs*. D_{50} = 0.194 mm) has improved stability and safety on the beach. The sand dumping on the beach has produced a small modification (< 30 cm) of the bathymetry (Figure 7b) so that there is hardly any variation in the wave heights reaching the beach (Figure 5 and Table 2). However, there has been a significant reduction in the number and intensity of eddies occurring in the nearshore zone

(Figure 5d, e and f), leading to a reduction in rip currents. The reduction in rip currents implies greater safety for beach users [4].

Regarding the potential sediment transport, it is known that the main mechanisms of sediment mobility are the action of waves and currents [8]. At Locos beach, a significant reduction in potential sediment transport is observed (Figure 6), which is due to the decrease in current velocity and the increase in the median sediment size [1]. The decrease in potential transport and the larger median sediment size leads to greater stability of the profile against storms (Figure 7c and 7d), with a reduction of the shoreline retreat of 4 m.

Conclusion

After modelling wave height, currents and potential sediment transport on a beach nourished with coarse sand, it can be deduced that the nourishment has been effective. The dumping of sand on the beach has not significantly altered the existing bathymetry of the beach, resulting in minimal changes to wave heights on the nearshore zone. However, the modification is sufficient to influence the direction and intensity of rip currents, improving safety on the beach and reducing potential sediment transport. In addition, the increase in median sediment size and the reduction in potential sediment transport improve the stability of the cross-shore profile in the face of storms. Therefore, in order to test future nourishment behaviour and better understand nearshore wave and sediment dynamics, the wave, rip currents and potential sediment transport in the nearshore zone should be modelled.

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UNCREWED AERIAL VEHICLES: AN INVESTIGATION OF THE PARAMETER INFLUENCES FOR COASTAL MONITORING

Marco Luppichini, Marco Paterni, Monica Bini

Abstract: Data and information obtained from low-cost uncrewed aerial vehicles (UAVs), commonly called 'drones', can be used to support coastal monitoring on erosion study. The Structure from Motion (SfM) techniques allow to reconstruction of a high-resolution Digital Elevation Model (DEM) useful to assess shoreline e dune mass, starting from the images acquired by UAVs. Flight procedures, acquisition methods and ground references are important parameters to be carefully managed to achieve the necessary accuracy. However, the size of the areas to be monitored and the frequency of measurements require demanding resources that can limit studies when they are insufficient. This work aims to investigate the best flight and processing settings for applying SfM for coastal monitoring. The parameters investigated are for example the drone type, flight height, ground control points (GCPs) position and post-processing parameters. The results of these evaluations and the proposed procedure are shown

Keywords: Coastal Monitoring, Drones, Structure from Motion

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Marco Luppichini, Marco Paterni, Monica Bini, *Uncrewed aerial vehicles: an investigation of the parameter influences for coastal monitoring*, pp. 761-772, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.66

Introduction

In recent years, the use of Unmanned Aerial Vehicles (UAVs) for high-resolution topographic surveys has increased significantly, yielding excellent results across various environments [1–9]. Among the techniques employed for topographic reconstruction using drones, photogrammetric surveys are the most used [10–21]. However, several factors can impact the accurate reconstruction of geometries within a model, including flat areas, water presence, and the availability of unidirectional models.

Coastal environments, in particular, exhibit all three of these factors, making them challenging terrain for Structure from Motion (SfM) models. SfM models play a crucial role in coastal monitoring, allowing quantification of seasonal variations, storm surge impacts, and human activities [5,6,8,22–27].

One way to enhance SfM models is through the use of ground control points (GCPs) for georeferencing and geometry reconstruction [17,28,29]. GCPs also help estimate errors in the three dimensions of the model, which is essential for understanding uncertainty in subsequent processing phases. However, the optimal number of GCPs required for precise and repeatable results over time remains scientifically unclear.

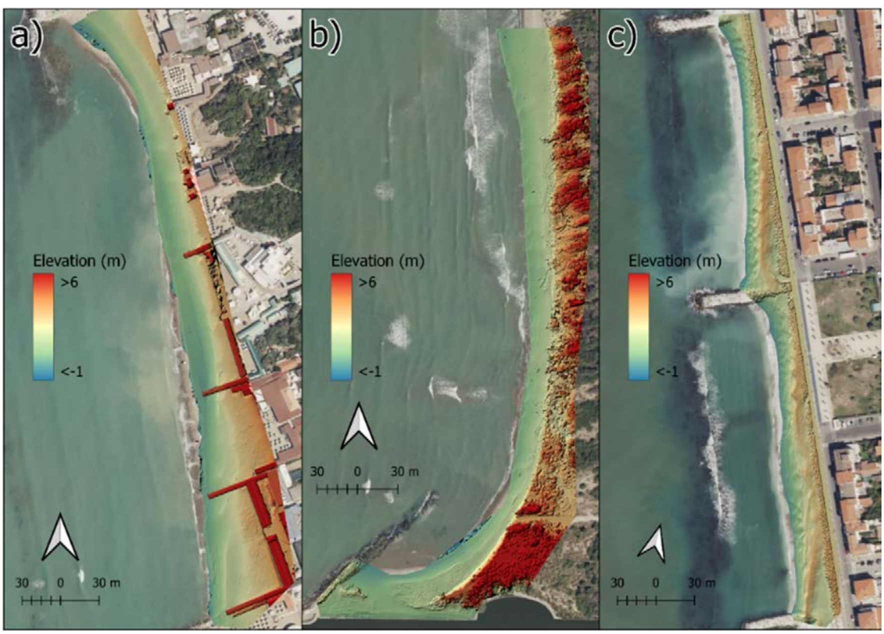

Figure 1 – Topographic characteristics of the three areas. The images contain Digital Elevation Models (DEMs) derived by DJI Phantom 4 at 30 m and using 20 GCPs for georeferencing: a) Area 1; b) Area 2, c) Area 3. Base map provided by Bing.

In this study, we analyze the effects of GCP positioning in three distinct coastal environments: low sandy beach (Area 1), sandy beach with dunes and vegetation (Area 2), and pebble beach with anthropic structures (Area 3: Figure 1). By sampling these areas using two drones at different flight heights and varying the number of GCPs during post-processing, we investigate error variations both spatially and in terms of average values.

Materials and Methods

The three study areas were surveyed using a DJI Phantom 4 Pro V2 and a DJI Mini 2. Flight plans for the DJI Phantom 4 were created using PIX4D Capture software, while for the DJI Mini 2, the Map Creator app for iOS was used. The flight plans were designed to achieve an 80 % overlap between acquired photos on each side and a pitch of 90° (orthogonal to the ground). Sampling campaigns were conducted at three flight heights: 30 m, 50 m, and 70 m.

The use of the DJI Phantom 4 and DJI Mini 2 can lead to differences in photogrammetric results, primarily due to variations in camera quality, sensor size, and stabilization. Equipped with a higher-resolution sensor and a 3-axis gimbal, the DJI Phantom 4 enables more detailed and stable image capture, enhancing the quality of the final model. Additionally, its superior focal length and stabilization reduce distortion and blurring, positively impacting overall survey accuracy.

In each study area, we strategically positioned a substantial number of markers. Specifically, we placed 55 markers in Area 1, 41 markers in Area 2, and 46 markers in Area 3. The marker positions were sampled using a Differential GPS Emlid Reach 2 with Real-time Kinetic (RTK) positioning.

We applied the Structure from Motion (SfM) technique using Metashape Professional v. 2.0.4. The analysis focused on error metrics provided by Agisoft Metashape for both control and checkpoint markers. The evaluation of the accuracy of the models is provided by calculating the Root Mean Square Errors (RMSE), as follows:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}((X_i - \overline{X_\iota})^2 + (Y_i - \overline{Y_\iota})^2 + (Z_i - \overline{Z_\iota})^2)}$$

where N is the number of control points; X_i, Y_i, Z_i are the observed coordinates of the i-th point; $\overline{X_\iota},\ \overline{Y_\iota}, \overline{Z_\iota}$ are the coordinates calculated by the model for the i-th point.

We systematically varied the number of control points, starting from three points (a minimum number to georeference a three-dimensional model) and gradually incorporating the full set of markers positioned in each study area. The marker not used as control points are used as check points. The first step use three markers as control points, the second step use four markers as control points and the procedure progress until the entire number of markers is used as control points. The choice of the markers used as control point is random. For this reason, the entire procedure is repeated thirty-five times generating more casual situations for a statistical analysis.

Results

The RMSE calculated for control points and check points related to changes in the Ground Control Points (GCPs) used are reported in Figure 3. As expected, the RMSE for control points is lower than that calculated for check points. The RMSE for control points shows a significant reduction when using 3 additional GCPs per hectare (equivalent to approximately 10 GCPs in the study areas).

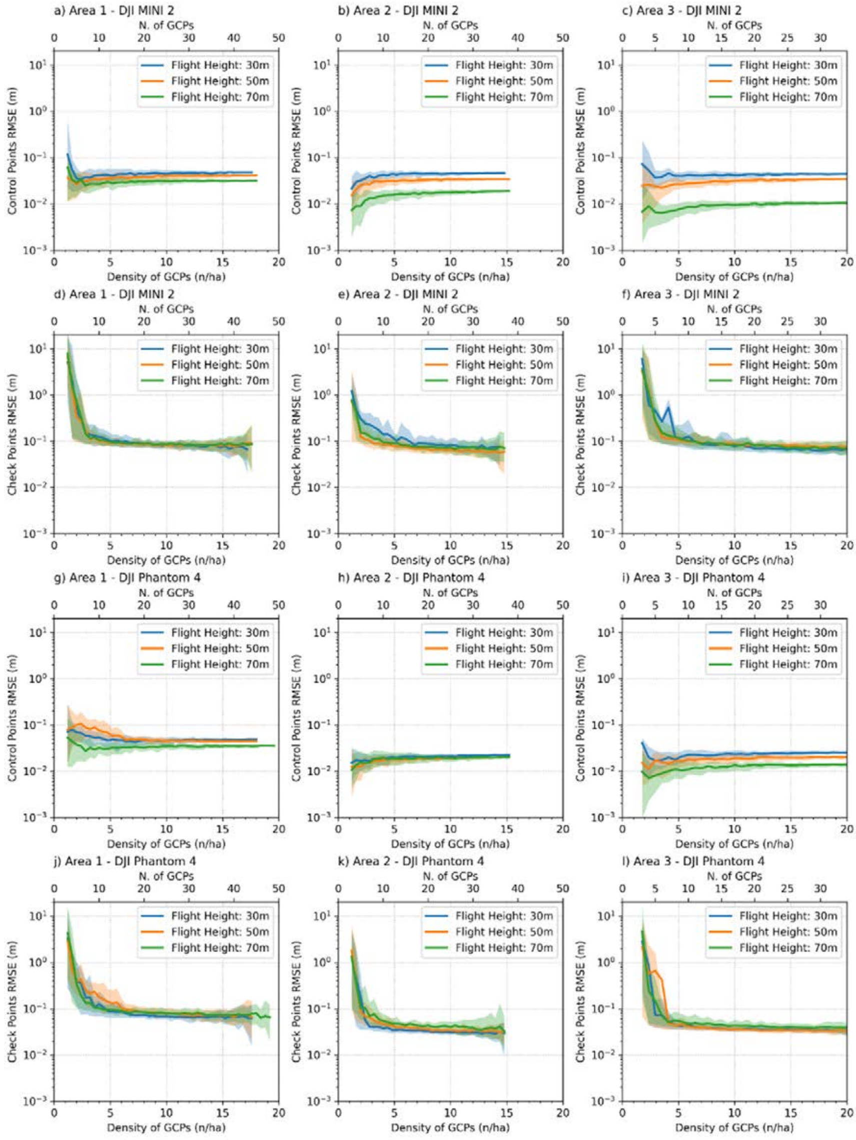

Figure 2 – Mean Square Errors (RMSE) of the control and check points.

In contrast, check points exhibit greater variability and require about 5 GCPs per hectare to achieve smaller errors. For Areas 2 and 3, the DJI Phantom 4 outperforms the DJI Mini 2, with the lowest RMSE observed for all flight heights. In Area 1, the two drones yield more comparable results, making it difficult to determine which equipment is superior. When using the DJI Mini 2, point clouds have the lowest RMSE for check points, approximately 7-10 cm across all investigated areas. The DJI Phantom 4 allows for point clouds with even lower RMSE (around 3-4 cm) for check points in Areas 2 and 3 (Figure 3).

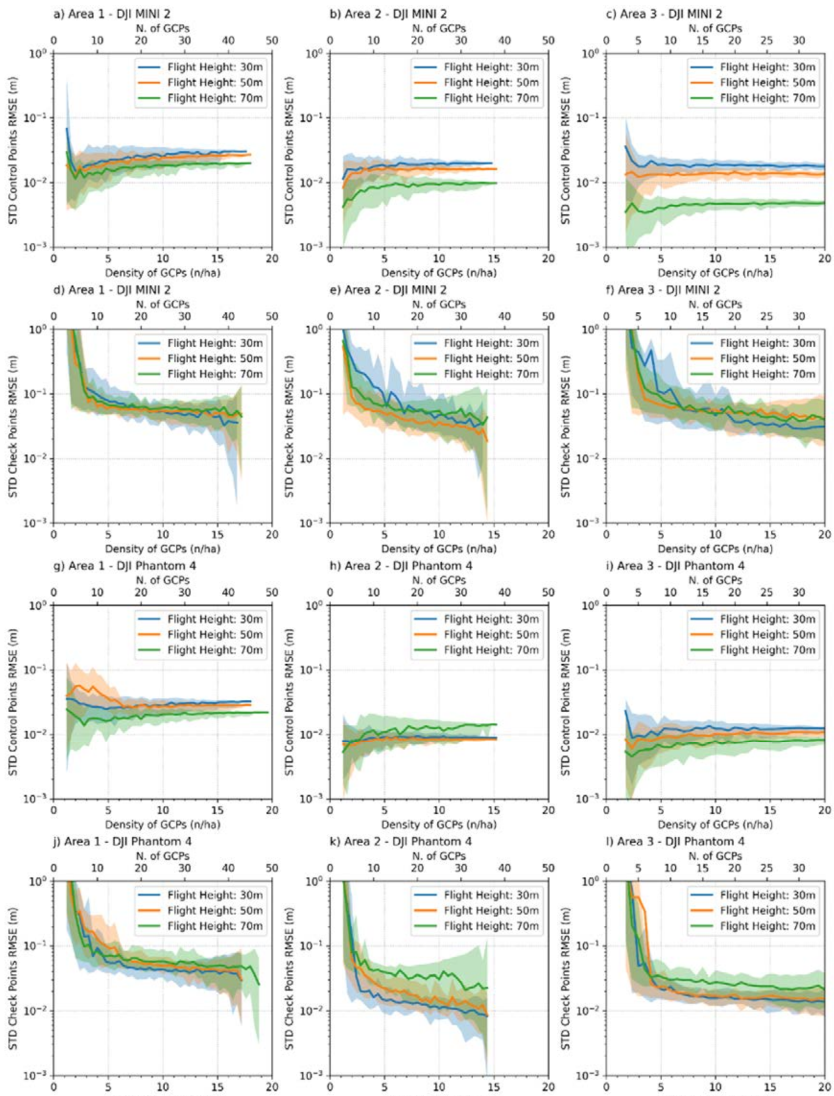

Figure 3 – Standard Deviation (STD) of the Square Errors of the control and check points.

The statistical mean of errors is an important parameter for assessing the quality of a photogrammetric model. However, it is equally crucial to investigate error variability along the model. This variability is influenced by factors such as control point positions, site topography, and the number of projections per marker (Figure 4). Even in this case, using more than 5 GCPs per hectare results in models with the lowest RMSE standard deviation for both control and check points, indicating less error variability. The DJI Phantom 4 achieves the lowest standard deviation values in Areas 2 and 3. Conversely, using the DJI Mini 2 introduces greater RMSE variability for both control and check points.

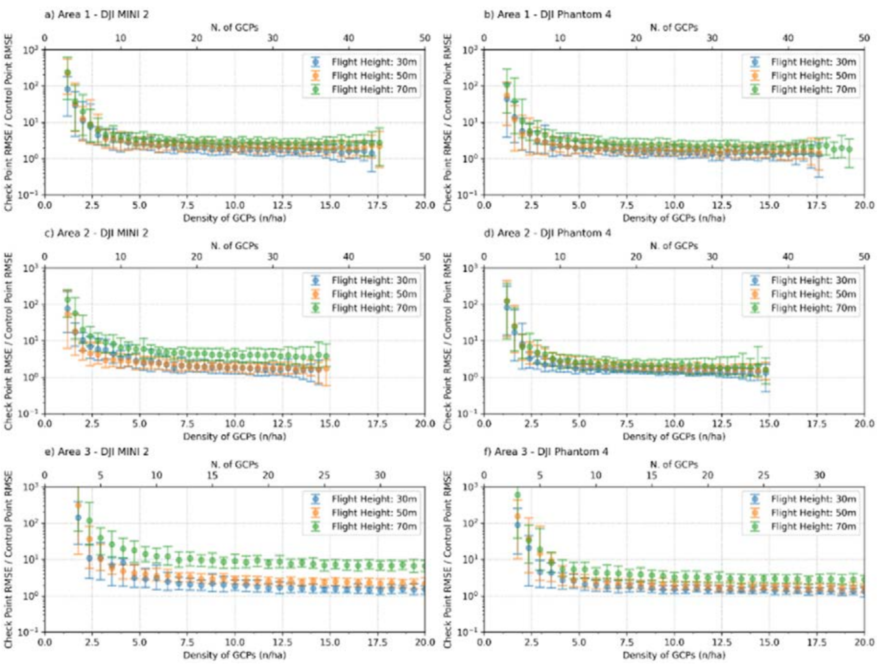

Figure 4 – Ratio between the RMSE checkpoint and the RMSE control point.

Ground Control Points (GCPs) were initially distributed evenly across the entire area of interest. For all the evaluated combinations, the selection of GCPs was random. However, since every combination was saved, it was possible to analyse the accuracy of the location of the GCPs. Figures 9 and 10 depict accuracy versus the average distance between GCPs (Figure 5) and the standard deviation of distances between GCPs (Figure 6). Averaged distances and standard deviations were calculated using all the GCPs employed in each combination.

Optimal accuracies for checkpoints were observed when GCPs within a specific combination had average distances of approximately 170 meters with standard deviations of about 100 meters. Remarkably, these values closely aligned with those obtained when statistics were calculated using all the GCPs. Averaged distances below 170 meters were associated with situations where the GCPs did not cover peripheral areas. In contrast, averaged distances exceeding 170 meters indicated fewer points but a well-distributed coverage across the entire area. Regarding standard deviations, values below 100 meters indicated that points were preferably grouped in small areas, whereas higher values suggested larger gaps between GCPs. While it is unsurprising that maximum accuracy is achieved when every ground point serves as a control, we observed that RMSE values degraded when points were limited in number, poorly distributed, or widely separated.

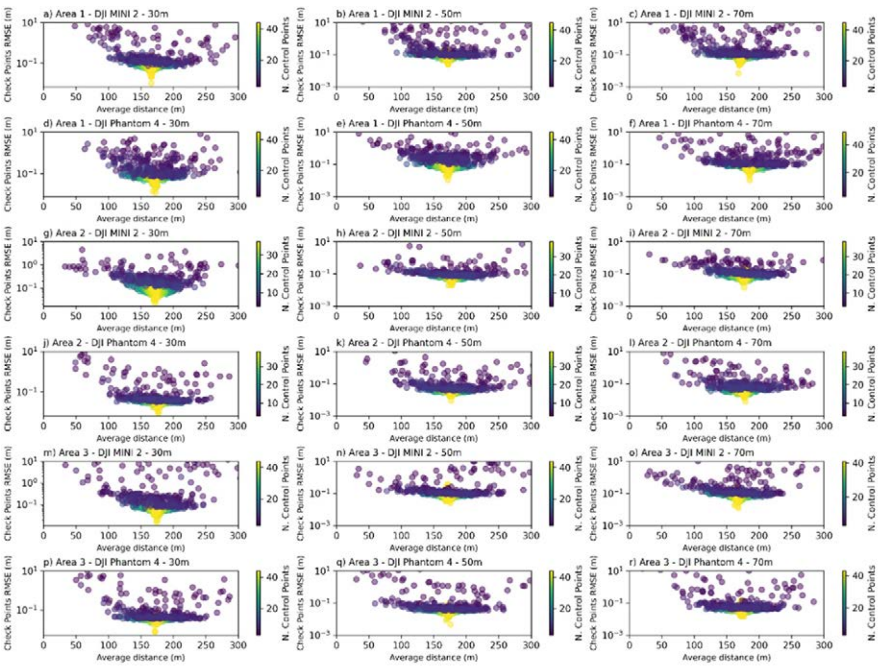

Figure 5 – Average distance between Control Point and Checkpoint Root Mean Square Errors (RMSE).

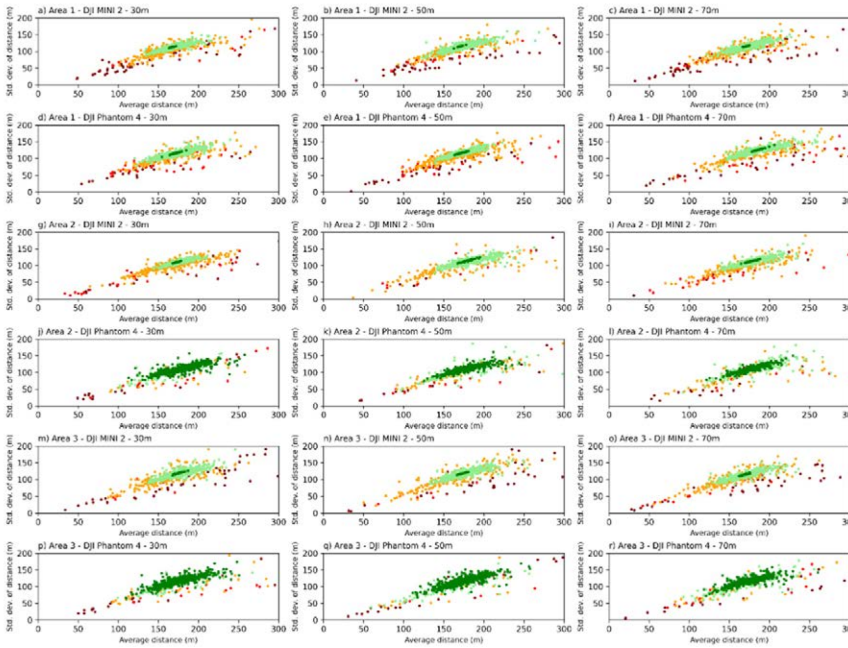

Figure 6 – Standard deviation of the distances between check points and Average distance between Control Points. The point colour indicates the Checkpoint Root Mean Square Errors (RMSE): the green points indicate an RMSE between 0 and 0.05 m; the light green points indicate an RMSE between 0.05 and 0.1m; the yellow points indicate an RMSE between 0.1 m and 0.5 m; the orange points indicate an RMSE between 0.5 m and 1 m; and the red points indicate an RMSE higher than 1 m.

Discussion and Conclusions

The geometric accuracy of the 3D SfM model strongly depends on the georeferencing strategy. The results of this study confirm that accuracy is influenced by the number of Ground Control Points (GCPs) used to adjust the point cloud. When using a small number of GCPs (fewer than 5 markers per hectare), the Root Mean Square Error (RMSE) at the checkpoint is very high, even exceeding several decimetres. Additionally, the variability along the model is also significant. However, by increasing the number of GCPs, the RMSE at the checkpoint decreases, reaching values lower than 10 cm, and the variability along the models decreases as well. This influence of GCPs on the models aligns with results from previous studies in other environments [17,30]. Both drones exhibit similar trends, but in two cases, the DJI Phantom 4 outperforms the DJI Mini 2, achieving a lower checkpoint error. These findings are consistent with results obtained in prior research [15,17,20,31,32].

It appears that further improvement of this value is not possible, regardless of the number of Ground Control Points (GCPs) used. Interestingly, flights at lower altitudes, which offer higher spatial resolution, exhibit accuracy comparable to that of flights at higher altitudes. One plausible reason for this phenomenon is that more distant points appear in a greater number of images, resulting in increased redundancy [17]. This observation could also explain the varying results obtained across the three study areas. In Areas 2 and 3, the DJI Phantom 4 outperformed the DJI Mini 2, while the results were similar in Area 1. Notably, in Area 1, the flights conducted with the DJI Mini 2 had a higher number of projections for each marker compared to those conducted with the DJI Phantom 4. Additionally, the increased redundancy in the photos may suggest improved performance of the Structure-from-Motion (SfM) technique [33].

This study has demonstrated that optimal accuracies are achieved when GCPs are uniformly distributed across the entire area. Strategies such as concentrating GCPs in specific areas, leaving gaps without GCPs, or focusing points on the periphery or centre do not yield good accuracy [17, 30, 34]. Ideally, the distribution of GCPs should follow a triangular grid, minimizing the maximum distance of each point to the nearest GCP.

When evaluating the geometric accuracy of a 3D model obtained through Structure-from-Motion (SfM), relying solely on ground points used as control is insufficient. This becomes critical when the number of GCPs is limited. While the RMSE (Root Mean Square Error) calculated at control points may appear extremely low (sometimes only a few millimetres) when using only a few points for control, a deeper analysis reveals that the actual RMSEs of the checkpoints can be much higher, even exceeding several decimetres. With a limited number of GCPs, the 3D model can adapt to the few geometric constraints introduced, resulting in low control residuals. However, increasing the number of GCPs reduces the ratio between RMSE at control points and RMSE at checkpoints, stabilizing at around 5 GCPs per hectare (Figure 4).

Figure 4 provides insights into estimating the RMSE at checkpoints when the number of markers is insufficient for control and checkpoint usage. Additionally, analyzing the Standard Deviation of the RMSE can enhance the assessment. Despite low variability in RMSE at control points with a small number of GCPs (as seen in Figure 3), the RMSE at checkpoints can still be significantly higher.

In summary, when using a small number of Ground Control Points (GCPs), the 3D models can be affected by high and variable RMSE (Root Mean Square Error) at checkpoints, while the RMSE at control points remains lower and less variable. This discrepancy can lead to an incorrect interpretation of result quality.

The study findings suggest that more than 5 markers per hectare (markers/ha) are necessary to achieve consistent and low errors. Interestingly, this requirement holds across different site characteristics (as observed in three distinct study areas) and regardless of the performance of the two different drones used.

In coastal environments, Structure-from-Motion (SfM) exhibits variability in error distribution along the model. Therefore, whenever feasible, it is crucial to associate a Digital Elevation Model (DEM) with an error map. This consideration becomes especially important during topographic and morphological analyses.

For future research, investigating the effects of other parameters—such as camera pre-calibration, which can reduce systematic errors in image alignment, and pitch angle adjustments, which may improve image overlap and coverage in complex coastal topography—could significantly enhance the accuracy and reliability of SfM models. These factors are especially important in coastal environments, where accurate topographic data is essential for understanding geomorphological changes.

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REMOTE SENSING FOR RECONSTRUCTION OF OMBRONE RIVER DELTA BEACH RIDGES

Irene Maria Mammì, Lorenzo Rossi

Abstract: The study area focuses on the Ombrone River delta (located in southern Tuscany, Italy), a wave-dominated delta formed over the last 2,500 years. Beach ridges, a characteristic depositional landform of wave-dominated deltas, extend across the entire coastal plain. These ridges are associated with ancient shorelines and reflect variations in river input and longshore transport. The objective of this study is to combine different remote sensing data to create a detailed map of the beach ridges in the area. Satellite images and aerial photos were utilized to differentiate beach ridges, while Unmanned Aerial Vehicle (UAV) photogrammetry and LiDAR (Light Detection and Ranging) data were also employed. A topographic survey was conducted to calibrate the UAV imagery and verify the accuracy of LiDAR data. The research demonstrates how high-resolution digital terrain models (DTMs), generated from LiDAR and UAV data, combined with other remote sensing sources, can be useful tools for reconstructing ancient morphologies, even over large areas like delta plains. A very detailed map of the beach ridges was produced, allowing for a better understanding of the delta's evolution through the analysis of the geometries of these landforms most of which have never been identified before.

Keywords: Beach ridges, river delta evolution, remote sensing data, satellite images, LiDAR.

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Irene Maria Mammì, Lorenzo Rossi, *Remote sensing for reconstruction of ombrone river delta beach ridges*, pp. 773-783, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.67

Introduction

Coastal landforms are constantly shaped by the interaction of various natural processes, including sediment transport by rivers, wave action, and changes in sea levels. Accurate mapping and monitoring of these landforms are crucial for understanding coastal dynamics and for supporting effective coastal management strategies.

This study focuses on mapping the morphologies of the Ombrone River delta (Grosseto), located in southern Tuscany (Fig. 1). According to the delta classification of Wright and Coleman [27] and Galloway [10], it is categorized as a wave-dominated delta.

The Ombrone catchment area covers approximately 3,495 km² and extends for 65 km, making it the largest river in southern Tuscany and the one with the highest discharge in the area [5]. The coastal plain of the delta covers about 350 km², with the main wave directions coming from the southwest, while longshore sediment transport moves in a south-to-north direction [1]. Land subsidence in the region has been measured at around 3 mm per year from 1891 to 1951 [20].

Variations in sediment input over time have caused both erosional and progradation phases. The erosion phase during the Middle Ages might be linked to population decline caused by the Black Death. The dating of the main beach ridges has been done by several authors using old historical maps and archaeological information [12]. The delta's river mouth reached its maximum progradation during the 18th and 19th centuries [6]. However, over the past 50 years, the Ombrone River delta has experienced severe erosion, with rates of up to 10 meters per year near the delta apex [18].

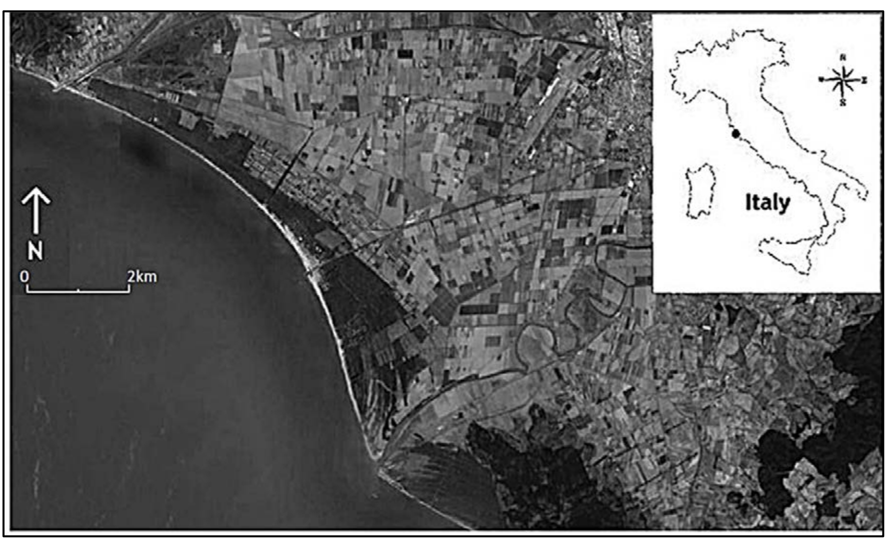

Figure 1 – Location map of the study area.

The complex of beach ridges extends across both wings of the delta in a northwest-southeast direction. The northern, longer, down-drift side has more widely spaced ridges, while the southern, shorter, up-drift lobe has closely spaced ridges running almost parallel to each other, terminating near the Collelungo rocky promontory, which marks the southern boundary of the delta plain.

Beach ridge plains hold valuable information on coastal evolutionary history, including long-term processes and significant events that occurred during the Holocene [21]. In this study, we approximate beach ridges to ancient shorelines [17]. Additionally, the spatial arrangement of beach ridges is related to changes in wave direction, sediment input, and available space for accommodation [23, 24, 25]. Reconstructing and mapping the geometries of beach ridges, sometimes through mathematical models [14], allows us to identify the erosional and accretional phases of the Ombrone River delta.

Remote sensing techniques have been widely used to study delta morphology changes.

This study has two main objectives: first, to deepen the understanding of the evolutionary history of the Ombrone River delta, located in southern Tuscany, by mapping beach ridges and analysing their geometries and distributions; second, to evaluate the advantages and limitations of various remote sensing techniques, including multispectral satellite imagery, LiDAR, UAV, and aerial photographs. This work specifically explores the effectiveness of these methodologies in reconstructing ancient morphologies and creating high-resolution digital models useful for studying deltaic dynamics.

This paper presents a study on the use of remote sensing data to map beach ridges on delta rivers [16, 22, 7], including the use of Synthetic Aperture Radar [9]. We will discuss the advantages and limitations of different remote sensing techniques and present our findings on their effectiveness for mapping beach ridges in deltaic environments. We will also discuss the potential applications of our findings for improving our understanding of delta morphology and their implications for sustainable planning and management.

Digital terrain models (DTMs), derived from LiDAR and UAV point clouds, provide high-resolution and accurate 3D metric information. These models allow for height analysis using cross-sectional profiles from the 3D data. The processing of satellite images and related transformation algorithms enables the enhancement of otherwise hidden or subtle morphologies, such as inter-ridge features.

The integrated use of various remote sensing techniques described here thus addresses both challenges of this study: providing a detailed map of beach ridges while also assessing the utility of each method in obtaining morphological data and identifying features that reflect the delta’s evolutionary processes.

Material and methods

In this study, data acquired from both active and passive remote sensors were utilized. Various satellite images were processed, including Landsat TM and Landsat ETM+ (from 1986 to 2002), Quickbird (2004), Landsat 8 (2015), and

Sentinel 2a (2017). Additionally, some Google Earth images were used. The satellite images had varying spatial resolutions: Landsat with 30 m, Sentinel 2a with 15 m, and Quickbird with 2.44 m resolution.

The images were acquired based on weather and seasonal conditions to achieve better textural discrimination based on soil wetness. All images were georeferenced using the UTM ED50 coordinate system and processed using ENVI 4.5 to extract geomorphological information from the study area.

To process the multispectral satellite images, several steps were followed: contrast stretching, density slicing, and the creation of RGB color composites from the original bands. In addition, the Normalized Difference Vegetation Index (NDVI), Tasseled Cap Transformation (Brightness, Greenness, and Wetness) [8], and Principal Component Analysis (PCA) were applied. The use of satellite images with varying resolutions and from different time periods allowed for an extended search of beach ridges through processing with multiple algorithms. For example, lower resolution but older Landsat images enabled the identification of certain previously unobserved forms in areas later affected by human activity or converted to agricultural use. In addition, lower resolution, in some cases, proved beneficial for distinguishing large-scale morphologies such as beach ridges.

Some results of these processes are shown in Figure 2.

Aerial photographs were also used for beach ridge mapping, including images from 1947 and 1954 (from RAF and GAI flights). These images were georeferenced by comparing them with regional maps (CTR 1:10000) using about 15 Ground Control Points (GCPs). The 1947 aerial photos were particularly useful for mapping the final portion of beach ridges close to the river mouth, which are now eroded.

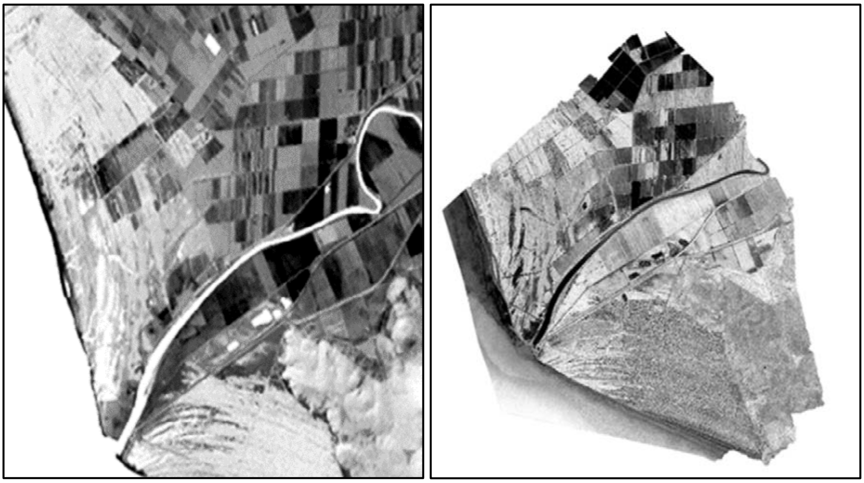

Figure 2 – Left: Wetness image from Landsat TM 5 acquired on February 1st, 1987, on the Ombrone river delta; Right: PCA image from Quickbird acquired on August 29th, 2004.

Additionally, three-dimensional data were acquired using LiDAR and UAV systems, which provided valuable information for generating cross-sectional profiles. LiDAR technology determines the distance between the ground and sensors by measuring the time it takes for a transmitted energy pulse to return to the LiDAR sensor [15]. The first LiDAR return typically corresponds to the top of tree canopies, while the last return corresponds to the ground, allowing the vegetation to be filtered. This method is especially helpful when morphologies are obscured by vegetation, as is often the case with beach ridge plains and dunes.

LiDAR data, provided as open data by the Ministry of the Environment and the Protection of the Territory and Sea in 2008, were processed into DTMs and DSMs with 1x1 meter and 2x2 meter resolution near the coast (Fig. 3).

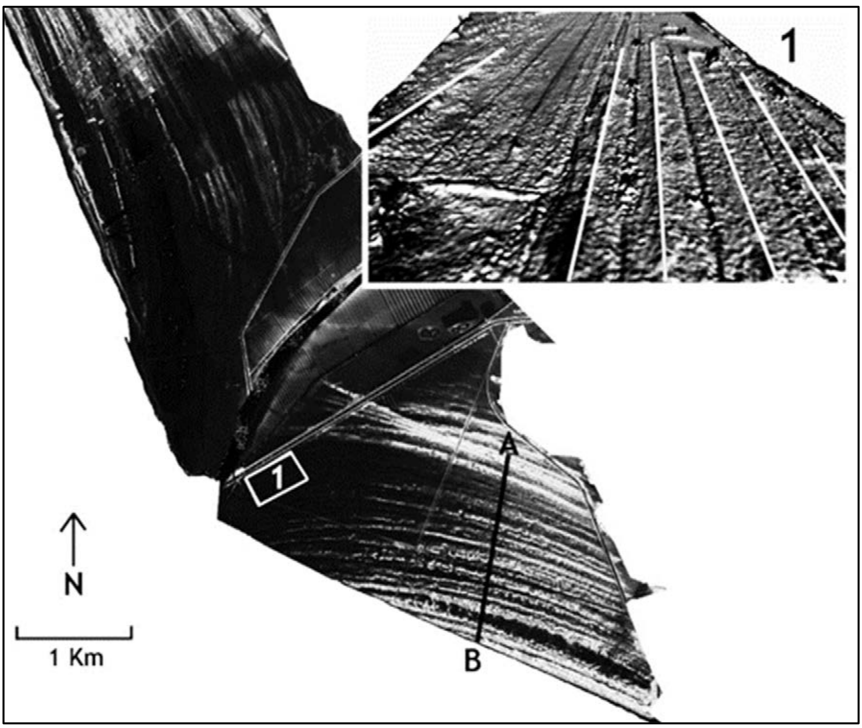

Figure 3 – LiDAR DTM and a detail of UAV survey performed in Area 1 with small beach ridges enhancement. AB LiDAR profile in black.

In 2016, a topographic survey was conducted to establish Ground Control Points (GCPs) for the UAV survey and to verify the accuracy of LiDAR vegetation filtering. Eighty points were surveyed using a total station, and these were compared with the remote sensing data, yielding a vertical accuracy (Root Mean Square Error, RMSE) of 22 cm.

UAV-based photogrammetry is a method used to obtain DEMs and orthoimages of the area being studied. In this case, a DJI Phantom 3 drone equipped with a 12.4-megapixel non-metric camera with a 14 mm F/2.8 lens was used, offering a diagonal viewing angle of 94°. The camera was set to take one image per second automatically. The flight altitude was selected to achieve images with a ground resolution of less than 5 cm. UAV-derived orthophotos were captured in 2016, from a flight altitude of approximately 60 meters. For ortho-photo and DEM georeferencing, 29 ground control points were measured using differential GPS.

The UAV survey area covered about 1 km², located in the southern lobe of the delta near the river mouth, where smaller beach ridges are present, and vegetation is sparse (Fig. 3). The survey aimed to highlight these small landforms, which were difficult to distinguish using other sensors such as LiDAR. Image processing was performed primarily with Metashape and Pix4D software, which allowed for image correction, orientation, point cloud extraction, and the production of an ortho-photo mosaic. A DSM with a 10 cm grid spacing and vertical accuracy (RMSE) ranging from 3 to 5 cm was processed using ArcGIS 9.3. The assessment of accuracy depends on camera resolution, flight altitude and speed, and the number of GCPs. All DTMs were later processed using ArcGIS 9.3 algorithms, such as Slope, Aspect, and Topographic Position Index [26, 13], to highlight coastal morphologies and perform morphometric and statistical analyses.

Results

Satellite images were processed using Principal Components Analysis, Tasseled Cap Transformation (Brightness, Greenness, and Wetness), and corresponding color composites. These analyses showed that the near-infrared and red wavelength bands provided the most information about the natural environment. Based on image processing and data analysis, many previously unknown beach ridge morphologies were identified, alternating with wet inter-ridge swales. These techniques allowed for the recognition of beach ridges that were not visible through LiDAR, UAV data, or aerial photographs.

Additionally, the DTM created by the UAV, with its 0.1x0.1 m resolution cells, allowed the digitization of smaller morphologies, especially those near the river mouth. Finally, LiDAR-derived DTMs enabled 3D reconstruction of the beach ridges and analysis of height variation across profiles.

The integration of these remote sensing techniques, applied over large areas, enabled the collection of substantial information about the distribution of beach ridges and the creation of a comprehensive beach ridge map (Fig. 4).

Using high-resolution 3D models, we identified various morphological features that reveal delta evolution dynamics, such as blowouts, beach ridge truncations, and geometric relationships between ridges and their height variations. Changes in beach ridge configurations and heights may be linked to reductions in sediment availability. High sedimentation rates typically result in smaller ridge dimensions, while slower deposition leads to larger ridges with wider swales [24].

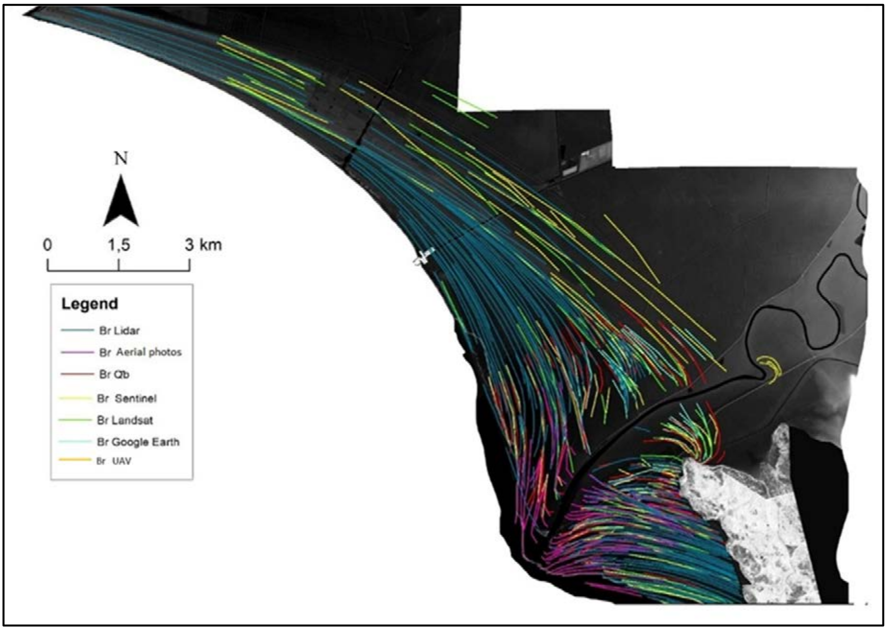

Figure 4 – Beach ridges mapped with different remote sensing technologies.

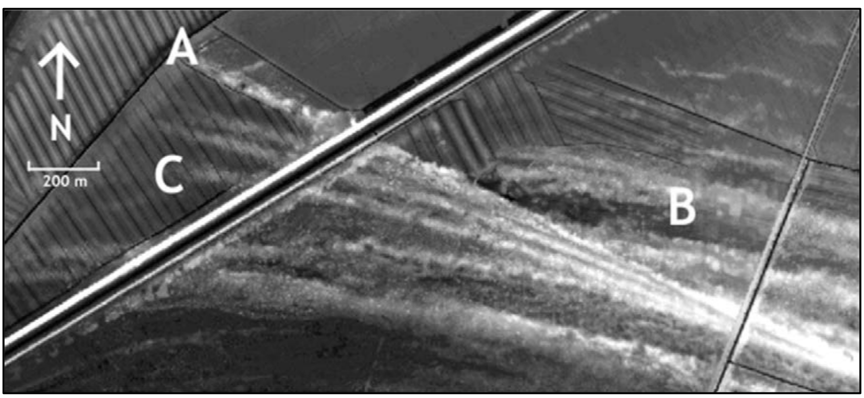

Figure 5 – LiDAR profile (AB) with Beach ridges evidence on the Southern wing of the delta.

Beach ridge profiles derived from the LiDAR 3D survey displayed variable elevations, reflecting different evolutionary phases. Taller beach ridges, such as those along the AB profile, correspond to major erosion phases, one occurring in recent times (after the 19th century) and another during the Middle Ages (Fig. 5, where the AB profile location is indicated in Fig. 3).

The geometric relationships between beach ridges also helped identify erosion and accretion phases (Fig. 6). Beach ridge truncations indicate periods of reduced river sediment input (Fig. 6B), while accretional phases at the delta apex are characterized by divergent ridge geometries (Fig. 6C). A straight coastline suggests a pronounced erosion period (Fig. 6A).

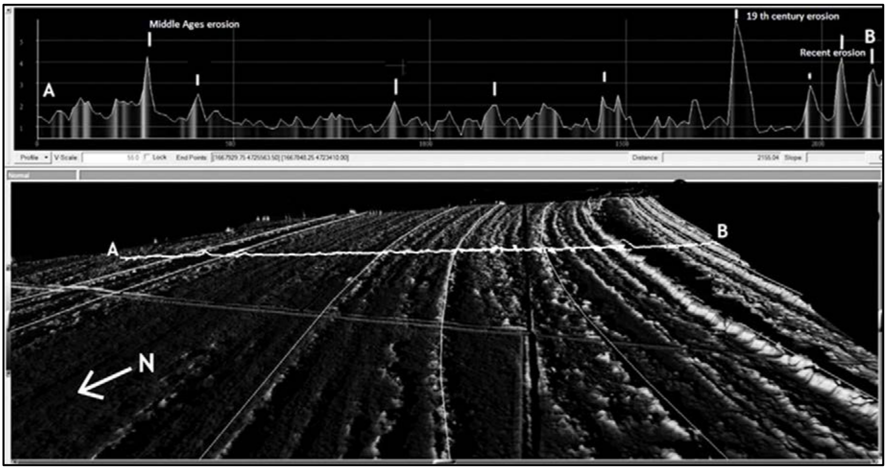

Figure 6 – Beach ridge geometries reflecting different evolution phases. Strong erosion with coastline straightening (A) and antecedent beach ridges truncation (B). Subsequent progradation (C).

Subsequently, the morphological differences between the ridges on the delta's two wings were explained through a morphometric analysis, which considered factors such as the number of beach ridges, their length, spacing, and orientation. These differences correspond to variations in local environmental conditions, such as river mouth migration or avulsion events.

Approximately 100 beach ridges were identified across the coastal plain. The angles between the ridges and the riverbank varied, with no constant values. Beach ridges associated with the Middle Ages erosion phase formed angles of about 90°, while others formed sharper angles. Ridges linked to the 19th-century erosion phase had smaller angles, ranging from 23° to 40°.

LiDAR and UAV-derived DTMs allowed for the measurement of ridge heights, with most ridges reaching up to 3 meters, while a few extended to about 8 meters. The distance between adjacent ridge crests varied from a few meters to hundreds of meters and differed between the delta's lobes, correlating with ridge height.

Mapping beach ridges using multi-temporal satellite images and high-resolution DTMs provided valuable insights into the evolution and morphological changes of the wave-dominated delta over time. The results demonstrate the successful identification and mapping of beach ridges within the Ombrone Delta region using satellite imagery. The classified images showed strong agreement with ground-truth data, validating the effectiveness of the methodology. The spatial distribution and morphological characteristics of the mapped ridges also offered important information on local coastal processes and landform evolution.

Conclusion

The high-resolution data obtained from active and passive remote sensing techniques significantly improved the reconstruction of beach ridge morphologies and provided valuable insights into the dynamics of the river delta lobes.

The integrated remote sensing study provided several new insights beyond what was previously known about the evolution of the Ombrone River delta:

1. Detailed beach ridge mapping: The combination of satellite images, LiDAR, and UAV data enabled a much more detailed mapping of beach ridges. New ridge morphologies were identified that were not visible in aerial photos or through LiDAR alone, especially near the river mouth.
2. Beach ridge height analysis: The DTMs from UAV and LiDAR allowed for a 3D reconstruction of the ridges, providing insight into height variations along profiles, which highlighted different evolutionary phases, such as periods of erosion and accretion.
3. Identification of new evolutionary phases: The study revealed previously undocumented phases of accretion and erosion. Ridge configurations and varying heights were linked to sediment availability and wave direction changes, offering a better understanding of sediment dynamics and the area's morphological shaping. Several accretion and erosion phases, which had not been fully identified before, were mapped. Different ridge heights were also observed and linked to variations in fluvial sediment input. Smaller ridges were associated with rapid progradation phases, where sediment quickly distributed along the shoreline, preventing the ridges from growing taller. In contrast, larger ridges formed when fluvial sediment input was lower, allowing more prolonged exposure to wind action, consistent with models in the literature.
4. Geometric relationships and coastal processes: The multidisciplinary approach visualized geometric relationships among beach ridges, revealing phenomena like ridge truncation (indicating reduced river sediment input) and morphological differences between the delta's two lobes, with one being more continuous and the other fragmented. The morphological differences between the two delta lobes can be attributed to the dynamics of a wave-dominated delta [4].
5. Wave angle impact on delta evolution: Morphometric analysis suggested that wave incidence angle contributed to an uneven coastline, especially visible in the northern lobe, where there are more wet areas and ridge discontinuities. One of the factors may be the angle of wave approach, which causes an uneven shoreline [3, 2]. On the northern, down-drift lobe, beach ridges are discontinuous, with more wet areas and ponds. In contrast, the southern lobe has more continuous and closely spaced ridges, with fewer wet areas. The reduced spacing between ridges in the southern lobe may be due to a greater

accumulation of sediment caused by the hydraulic "groyne" effect of the river flow [11, 19, 2].

We have therefore seen how various types of data were used, including high- and medium-resolution satellite images and three-dimensional models. DTMs proved extremely useful for obtaining profiles and elevation information, while aerial photos and satellite images were indispensable for landform mapping and for identifying beach ridge morphologies associated with wet areas. The combination of these different data types enabled the visualization of the geometric relationships between beach ridges. Some challenges arose from managing the diverse datasets and analysing information from various sensors to draw consistent conclusions about the identification of morphological elements

Finally, the use of GIS proved highly beneficial for data management and analysis. An integrated, multidisciplinary remote sensing approach was essential for producing a detailed map of the Ombrone River delta's morphology, which will serve as a valuable resource for future research on coastal evolution.

In summary, the study offered a much richer, more precise view of the delta's morphological structures and its accretion-erosion processes, leading to a more comprehensive understanding of the Ombrone delta's evolutionary dynamics and providing a valuable foundation for future studies.

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MAPPING COASTAL VULNERABILITY AGAINST EROSION ALONG THE ALICANTE COASTLINE, SPAIN

José I. Pagán, Pablo Ortiz, Isabel López

Abstract: The assessment of coastal vulnerability helps prioritize investments to increase coastal resilience. This work aims to map the vulnerability of a 12 km coastal stretch of the province of Alicante, Spain. It is an area where natural spaces with wetlands and important dune ridges alternate with highly urbanized spots. The method calculates a Coastal Vulnerability Index (CVI) through three main indicators: geomorphology (geology, coastal slope, erosion rate, beach width and dune width), hydrodynamics (significant wave height, mean tide range and flood level indicator) and vegetation variables (state of seagrass meadows, depth and width of these meadows and backshore area covered by vegetation). The coastal strip studied was divided into sections of 200 m, obtaining the CVI on each one. The vulnerability of each variable was evaluated from 1 (Very low) to 5 (Very high) and the overall CVI was obtained. The higher values of CVI were detected in the urbanized areas (41 % of the sections). Dune ridges serve as barriers to flooding and reduce erosion. A sufficient beach width and slope are crucial to preventing flooding during extreme weather events.

Keywords: CVI, coastal vulnerability index, coastal erosion, shoreline, coastal management

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

José I. Pagán, Pablo Ortiz, Isabel López, *Mapping coastal vulnerability against erosion along the Alicante coastline, Spain*, pp. 784-793, DOI: 10.36253/979-12-215-0556-6.68

Introduction

Coastal areas are currently facing increased vulnerability, exacerbated by coastal erosion - a natural phenomenon - which increases combined with the effects of climate change, extreme events and human activities [11]. This situation not only compromises the stability of coastlines, but also threatens the well-being of the communities that inhabit these regions. Furthermore, the potentially massive impact of climate change on coastal zones, which is globally recognized, should be contemplated [18]. The Mediterranean Sea region is considered one of the main hotspots, due to the agglomeration of residents, tourists, urban growth, infrastructure, and biodiversity in its coastal areas [8].

In addition, coastal erosion is one of the most important problems on a global scale, with about 70 % of the world's sandy beaches undergoing erosion [3]. However, it is not easy to recognize whether a coastal system is affected by erosion processes. It can be influenced by a variety of factors, each one with different underlying causes: natural factors like the morphology or the composition of the sediments, wave energy and littoral drift or anthropic actions such as ports or beach nourishments [2, 15, 19, 23].

Moreover, the disappearance of dune areas deserves special attention, as they constitute a natural reservoir of sand for beaches and are essential for the creation and stabilisation of wetlands and shorelines. In many places they have been destroyed for the construction of promenades and buildings [9]. These environments have specialised flora and fauna, providing unique ecological services such as flood control and storm protection [21]. Likewise, the presence or absence of marine phanerogams such as *Posidonia oceanica* can be of great relevance to the coastline. Several studies have demonstrated their influence on the nature and dynamics of coastal sediments, playing a crucial role in the physical equilibrium of a large part of the Mediterranean coasts, both by reducing incident wave energy and by protecting against coastal erosion [6, 7]. The three-dimensional structure of the rhizomes constitutes a certain reinforcement of the sandy sediment of the submerged beach which, together with the roots and leaves, slows down the sedimentary movements of the seabed, causing changes in the submerged beach profile to be considerably slower than they would be in the absence of the meadows [14].

Thus, the Spanish Mediterranean coastline is a region of special interest, since it has been subject to sociopolitical, economic and environmental changes at local, national and even international scales since the 1960s [22]. A significant modification of the morphology and, consequently, the coastal dynamics of the area have been detected [28]. To tackle this problem, a growing interest in understanding and including vulnerability studies in coastal zone management policies has arisen [1, 26, 29].

The Coastal Vulnerability Index (CVI) is a synthetic index to assess coastal vulnerability [10]. A series of variables are calculated to evaluate the relative vulnerability of different stretches of a coastal area. Regarding the application of the CVI in the Mediterranean area, a study was conducted to map the relative vulnerability of the western Peloponnese in Greece for a coastline length of about

50 km [5], while the Egyptian Mediterranean coast was also examined [13]. In Italy, it was applied on the Apulian coast [25] and in Spain across the 160 km coastline of the province of Barcelona [17].

The main objective of this work is to map the coastal vulnerability of a 12 km stretch of the Costa Blanca, in the province of Alicante, Spain. It is an area where natural beaches, wetlands and important dune ridges alternate with highly urbanized spots, detecting relevant erosion of the beaches in some sections. A CVI adapted to the area will determine the vulnerability of coastal stretches based on existing data and a reliable approach, which is critical for developing appropriate coastal management strategies.

Materials and Methods

The area of study is located in the province of Alicante, southeast of Spain. Particularly, a stretch of 12 km from Cape Santa Pola to Alicante city was studied, encompassing the beaches of El Carabassí, Arenales del Sol, El Atlet, El Saladar - Urbanova and Agua Amarga. (Figure 1). This is mainly a sandy coast with a relevant dune ridge, interrupted by the urban developments of Arenales del Sol and Urbanova, which is also next to the salt marsh of Agua Amarga.

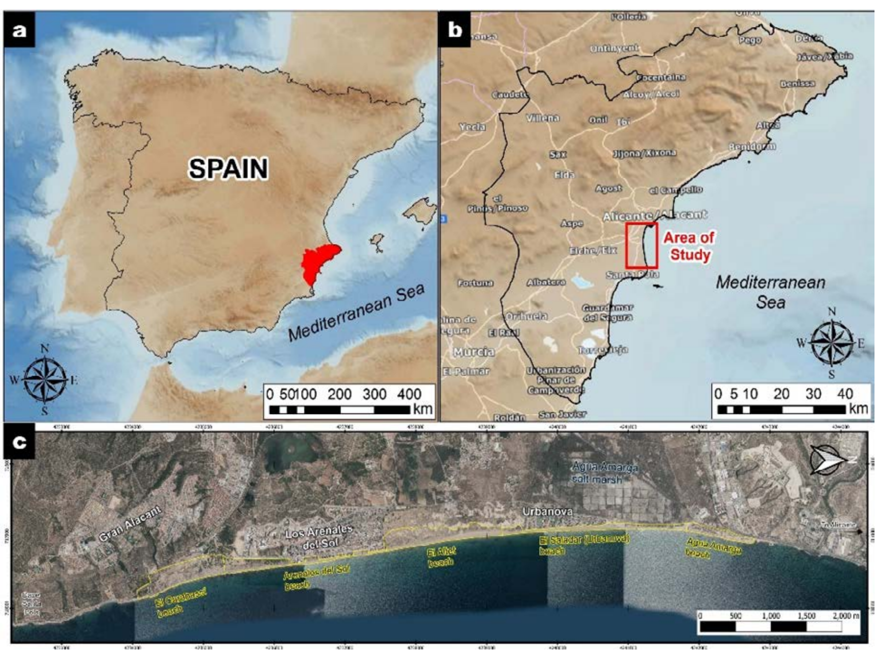

Figure 1 – a) Province of Alicante, Spain. b) Location of the area of study and c) detail of the coastal stretch studied with beaches (yellow) and urban developments (white).

Data used to assess coastal vulnerability were grouped into three main indicators: geomorphology (coastal slope, erosion rate, beach width and dune width), hydrodynamics (significant wave height, mean tide range and flood level indicator) and vegetation variables (presence of seagrass meadows, depth and width of these meadows and backshore area covered by vegetation). A total of 11 variables were considered.

All the required data were downloaded from open and official sources and stored within a geographic information system. For this research, data sources were the websites of the Valencian Spatial Data Infrastructure, IDEV (https://geocataleg.gva.es/#/?lang=spa), Ministerio para la Transición Ecológica y el Reto Demográfico (https://www.miteco.gob.es/es/costas/temas/proteccion-costa/ecocartografias/ecocartografia-alicante.html) and Puertos del Estado (https://www.puertos.es/en-us/oceanografia/Pages/portus.aspx). Thus, a geodatabase in GeoPackage format was created containing all the geospatial information collected in the ETRS89 / UTM zone 30N coordinate system.

Aerial images from all available years were obtained: 1929, 1956, 2002, 2005, 2007, 2009, 2012, 2014, 2017, 2018, 2019, 2020, 2021, 2022 and 2023, for a total of 94 years of study. These images were downloaded in TIFF mosaics of panchromatic black and white colour (1929-1956), a mosaic of natural colour (RGB) for 2002 - 2014 and natural and false colour infrared (RGBI) orthophotographs for the period 2017 to 2023, with a spatial resolution of 25 cm. The use of RGBI images enabled the calculation of the Normalized Difference Vegetation Index (NDVI), an effective indicator for assessing the greenness, density and health of vegetation in each pixel of an image, as well as to map the vegetation cover of an area (Figure 2).

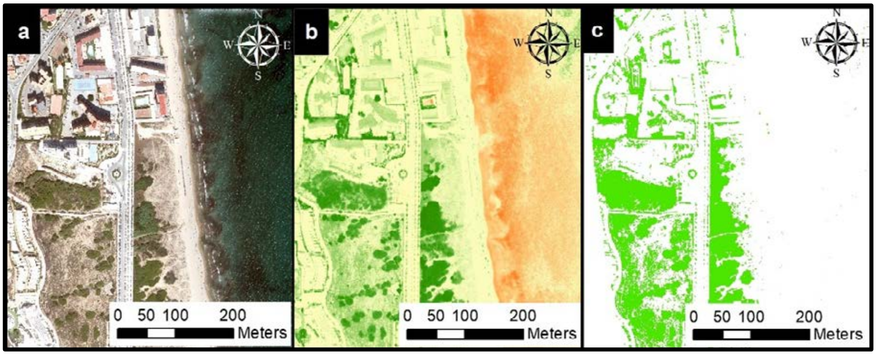

Figure 2 – a) RGB Orthoimage of 2023. b) NDVI for 2023 and c) Area covered by vegetation (green colour) extracted from orthoimage and NDVI.

A Digital Terrain Model (DTM) in raster format with 1 m of spatial resolution, derived from a LiDAR survey carried out in 2016, were used. Bathymetry obtained with a Multibeam sounder at a 1:1000 scale from 0 to – 40 m depth was also collected, as well as other cartography (geological maps, biological underwater species). The swell data were obtained from the SIMAR node 2078099. The SIMAR data is an hourly record of wave height, swell period, and direction from 1958 to the present.

The coastal strip studied was divided into sections spaced 200 m apart, obtaining the CVI on each one from representative transverse profiles created perpendicular to the shoreline, from the baseline to the bathymetric – 20 m. The vulnerability of each variable was evaluated from 1 (very low) to 5 (very high), according to the ranges of Table 1.

Table 1 – Vulnerability ranges for each variable.

Variable (Vulnerability)	Very Low (1)	Low (2)	Moderate (3)	High (4)	Very High (5)
a. Geology	High cliff (> 20 m)	Medium – cliff (20 –10 m)	Low cliff (5 – 10 m)	Gravel / pebbles beach	Sand beaches, marshland
b. Coastal slope (%)	> 12	12 - 8	8 - 4	4 - 2	< 2
c. Erosion rate (m/yr)	> +1.5	+1.5 –+0.5	+0.5 – -0.5	-0.5 – -1.5	< -1.5
d. Beach width (m)	> 100	100 – 60	60 – 30	30 - 15	< 15
e. Dune width (m)	> 100	100 – 75	75 – 50	50 - 25	< 25
f. Significant wave height (m)	< 1.0	1.0 – 2.0	2.0 – 3.5	3.5 – 5	> 5
g. Mean tide range (m)	< 0.2	0.2 – 0.4	0.4 – 0.6	0.6 – 0.8	> 0.8
h. Relative flood level (m)	< -1.5	-1.5 – -0.5	-0.5 – +0.5	+0.5 – +1.5	> +1.5
i. Presence of seagrass meadows	*P. oceanica* meadow	*P. oceanica* with other species	*P. oceanica* in regression	*P. oceanica* degraded	Absence of *P. oceanica*
j. Upper depth of these meadows (m)	< 4.0	4.0 – 6.0	6.0 – 9.0	9.0 – 12	> 12
k. Backshore area covered by vegetation (%)	> 80	80 – 60	60 – 40	40 – 20	< 20

The overall CVI was obtained as the square root of the product of the value of vulnerability for each variable divided by the number of variables (Equation 1)

$$\mathrm{CVI} = \sqrt{\frac{a \cdot b \cdot c \cdot d \cdot e \cdot f \cdot g \cdot h \cdot i \cdot j \cdot k}{11}} \qquad (1)$$

Results

A total of 60 transects were obtained along the 12 km of the coast studied. The overall CVI shows that 23 % of them have “Very High" vulnerability, 18 % “High”, 23 % “Moderate”, 16.4 % “Low” and 19.7 % “Very Low". The higher values of CVI were obtained on the urbanized areas of the beaches of Arenales del Sol and El Saladar (Urbanova), whereas the lower ones were obtained in the El Carabassí beach (Figure 3).

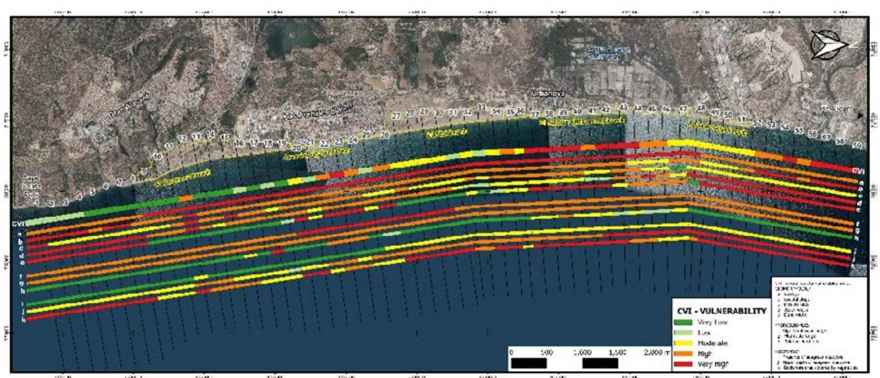

Figure 3 – Overall CVI obtained and vulnerability for each variable.

Analysing the vulnerability by variables, the majority of the sections correspond to sandy beaches or marshlands, which is the most vulnerable category. Coastal slope is typically between 2 and 4 %, which means a High vulnerability. Regarding the erosion rate obtained, 59 % of sections have an average erosion rate near 0 m/year, so although it means a stable situation, have a Moderate vulnerability. However, in 39 % of transects erosion rates of 1 m/year have been identified, which represents a High vulnerability.

Lower values of vulnerability were observed in transects with dunes and more than 35 m of beach width (Figure 4). There are two main stretches without dunes, coinciding with the urban developments of Arenales del Sol (sections from 20 to 26, which represent a length of 1200 m) and Urbanova (37 – 42, 1000 m).

Regarding hydrodynamics variables, significant wave height and mean tide range is almost the same for all transects, 4.71 m and 0.69 m, respectively. This means a High vulnerability. Only in front of Arenales del Sol beach, the wave height reaches more than 5 m, coinciding with one of the most exposed areas (Figure 3) with the lowest beach width (Figure 4).

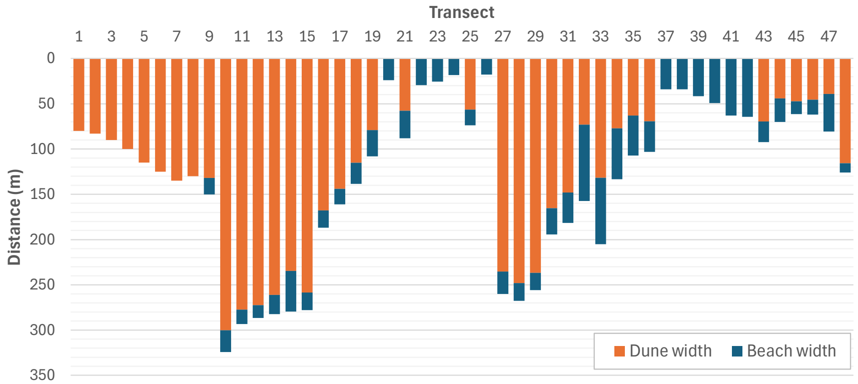

Figure 4 – Average beach and dune width for each transect during the last 3 years.

Relative flood level refers to the highest water level (the sum of the combined action of the astronomical tide, meteorological tide and run-up) reached during a coastal flood event, compared to the maximum height of the beach profile. 72 % of transects have a value higher than -1.5, with an average value of – 5.0 m. These sections match the ones with dunes. However, in 13 sections the flood level is higher than the maximum height of the profile, so achieve High or Very High vulnerability according to the ranges of Table 1.

Vegetation variables are also relevant. Near the coastline of the study area, *Posidonia oceanica* meadows were detected in different conditions. In 60% of the sections *P. oceanica* in regression were observed, whereas in the remaining 40% *P. oceanica* meadows were observed in a good state. However, it is also relevant to note the depth at which these meadows appear. In 18 sections, the upper depth is higher than 12 m, so it means a Very high vulnerability. In 22 sections is on average 10.6 m (High vulnerability) and in the 20 sections remaining is 7.7 m (Moderate vulnerability).

Finally, the backshore area covered by vegetation was studied. The presence of vegetation on the dunes is useful for reducing erosion and dissipating wave energy in case of extreme events. In our case, only 12 sections have between 40 - 60 % of the backshore area covered by vegetation, with 11 sections ranging between 20 - 40 % and 9 sections with lower than 20 % of its surface covered.

Discussion

Mapping coastal vulnerability using an index such as CVI enables coastal managers to have a clear idea not only of the most vulnerable locations in a coastal stretch but also of the variables that affect more. The results of our study are totally in line with other studies carried out on the Mediterranean coast [13, 17, 25]. Moreover, the assessment of coastal vulnerability helps prioritize investments to increase coastal resilience [5]. The method followed in this research has studied 11 variables obtained using geographic information systems (GIS) and can be easily applied in other areas with available data. Having reliable, open access sources with a sufficient period of collecting data is key to performing accurate analysis [27], but certainly is not a common situation in many countries, relaying expensive data acquisition such as high-resolution aerial images or LiDAR DTMs in governmental initiatives, which are scarce [20].

The analysis of the different variables used to calculate the CVI enables us to highlight those on which it is possible to act anthropically to reduce vulnerability in that section. There are variables such as geology, coastal slope, tidal range or presence and depth of marine phanerogams on which it is almost impossible to interfere. However, there are others such as beach and dune width, flood level, backshore vegetated surface or even incident waves on which it has been developed techniques that can be used to reduce their impact on the coast.

Relative flood level indicates the importance of dunes and coastal slope to prevent flooding during extreme events, being the most vulnerable transects the ones without dunes ridges due to urbanization developments (Figure 3 and Figure 4). The inclusion of vegetation variables, particularly those related to the marine phanerogams like *Posidonia oceanica*, as well as dune vegetation coverage, are crucial as an indicator of its capability to dissipate wave energy, fix sediments and reduce beach erosion. Beach nourishment projects should consider this, not only focusing on gaining beach width but also restoring or creating dunes ridges fixed using indigenous species that facilitate sustainable management and reduce the need for costly interventions [12, 24].

The impact of urbanization and tourism on the coastal environment, especially in these vulnerable areas, should be also considered [4]. Managing erosion-induced problems in urbanised areas is as important as maintaining natural environments safe from new developments [16]. In our study area, the destruction of the dune ridge by these urban developments, together with the beach erosion and the extreme maritime events causes these stretches to be the most vulnerable ones, while the natural ones, with the dunes protected and the beach not invaded by houses or promenades, have the lowest vulnerability.

Conclusion

Mapping coastal vulnerability using a CVI helps prioritize investments and actions to increase coastal resilience. A sufficient beach width and slope are key elements to prevent flooding during extreme weather events. Dune ridges serve as barriers to flooding and reduce erosion. The most vulnerable transects coincide with urbanised zones that destroyed dune ridges.

The methodology developed in this work has made it possible to identify the most vulnerable stretches, making it easier for coastal managers to prioritise investments for the adequate maintenance and protection of the coast which, due to climate change, will be increasingly necessary.

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CLIFF FAILURE PROCESSES AND LONGSHORE DISPERSAL OF SEDIMENTS, VRGADA ISLAND (CROATIA): INPUT FROM SFM PHOTOGRAMMETRY AND SEDIMENT CHARACTERISTICS

Kristina Pikelj, Nina Furčić, Frane Marković

Abstract: The coastal cliff on the Vrgada island is developed in Pleistocene aeolian-alluvial deposits which are subject to constant erosion. Digital Structure-from-Motion photogrammetry has been used to record and monitor the erosion of the cliff most of which occurs in the form of rockfalls. As a result, an L-shaped beach has formed. The eroded material is reworked and partially washed away by rain and waves. The prevailing waves are generated by the Scirocco wind (SE, and they transport the eroded material from the eastern to the north-western part of the beach. This transport direction is confirmed by heavy mineral analysis, including grain size, and by the carbonate content of the beach sediments. It is expected that the local input of terrigenous sediment may affect seagrass meadows and waterways. Continued erosion of the Vrgada cliff could jeopardize anthropogenic infrastructure and alter the island's coastline in the future.

Keywords: Adriatic, coastal cliff, beach, erosion, long-shore drift, SFM photogrammetry

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Kristina Pikelj, Nina Furčić, Frane Marković, *Cliff Failure Processes and Longshore Dispersal of Sediments, Vrgada Island (Croatia): Input from SFM Photogrammetryand Sediment Characteristics*, pp. 794-803, DOI: 10.36253/979-12-215-0556-6.69

Introduction

The Eastern Adriatic coast in Croatia is a high, steep and rocky coast developed mostly in carbonates deposited in Mesozoic [13]. This lithology combined with active uplift led to the development of karstic relief and visible tectonic structures along the coast. Under aforementioned conditions, typical coastal forms such as cliffs, wave-cut platforms and beaches are the exception, while steep and mostly inaccessible rocky coasts predominate, including tectonic cliffs and submerged karstic relief forms [13, 15]. However, during synsedimentary tectonics in the Mesozoic and Cenozoic, deeper basins were formed in which turbidites were deposited [16]. Today, these deposits, together with younger deposits, mostly loess, formed in Pleistocene, form the main bedrock of about 6 % of the Croatian coast [3, 10]. In these stretches of soft-rock coastal segments there are more cliffs and beaches which are currently subject to rapid erosion in some places [1, 12, 17].

One of these places along the Croatian coast is a small section of the Vrgada island. Although it is shown in older geological maps as a pure carbonate island, its north-eastern part contains strongly erodible clastic deposits (Figure 1). They outcrop today in the form of a ~15 m high coastal cliff and consist of aeolian-alluvial sedimentary sequence from the Pleistocene [1]. The cliff is subject to constant erosion, especially along its eastern steeper side. As a result of erosion, an L-shaped mixed gravelly-sandy beach has formed at the foot of the cliff [13]. The aim of this work was to investigate the coastal processes occurring along the cliff and beach in order to explain the main mechanisms of coastal evolution. The first part of the work refers to the cliff erosion and the beach formation, while the second shows the fate of the beach sediment in terms of longshore transport and sediment loss in the sea.

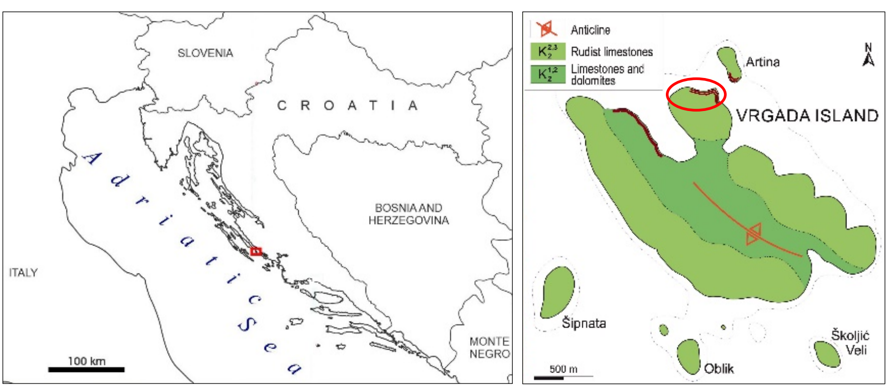

Figure 1 – Location map of the Vrgada Island (left) and carbonate lithology usually shown in old maps [9]. Pleistocene aeolian-alluvial deposits on the island are designated by the brown lines. Study area is shown in red oval.

Material and methods

During the cliff erosion monitoring between October 2022 and November 2023, three consecutive digital models were selected (October 2022; April 2023 and June 2023) to represent the typical processes on the cliff slope. The digital models were constructed using Structure-from-Motion digital photogrammetry in Agisoft Metashape software from 200-300 photos taken by a drone. The overlap of the photos was 80 % and the digital models were georeferenced with movable ground control points (GCPs). Their precise position was determined by virtual real-time kinematics of the reference station using a Trimble R8 GNSS receiver. The correction was carried out using the high-precise positioning service CROPOS (DGU; http://www.cropos.hr/). The horizontal and vertical accuracy of GCPS was 2 and 4 cm respectively. The accuracy of the digital models was within 3 cm.

First 3 cm of beach sediment was carefully collected at 9 locations (Figure 2) on a 40x40 cm square. The sediment was collected for grain size, heavy mineral fraction, and carbonate content analyses. Considering the second analysis, samples were collected as close as possible to the dominant grain size in each square to ensure representativeness, as suggested by [7]. For grain size analysis, sediment samples were air-dried and 100 g of each subsampled sediment was wet sieved using 7 standard sieves with mesh sizes ranging between 4 mm and 63 μm at 1 phi interval. Granulometric parameters were calculated according to [6] using the Gradistat Excell package [2] and the sediments were classified according to [5].

The carbonate content in each powdered bulk sample was calculated from the volumetric measurement of CO_2 released after treatment of each sample with 1:1 diluted HCl acid, using the Scheibler apparatus.

For heavy mineral analysis, additional subsamples were separated from the bulk samples and sieved through 63 μm and 125 μm mesh sieves to obtain a very fine sand fraction. Carbonate particles were dissolved with a mild acid (5 % acetic acid - CH_3COOH) and the samples were treated with 15 % hydrogen peroxide (H_2O_2) to remove organic matter. The 63÷125 μm fraction was separated with sodium polytungstate (SPT), density 2.90 g/cm^3, and centrifuged at 2500 rpm for 5 min. The grain mounts were prepared with Canada balsam (n = 1.54). The heavy minerals were counted using the ribbon counting method. At least 300 grains of transparent heavy minerals were counted per sample.

In addition, the results of grain size and carbonate content analysis published by [13] were also included in this study and discussed in order to obtain the overall picture of the fate of the eroded cliff sediments. As described in [13], the marine sediment was analysed for grain size and carbonate content in the same way as described above. The only exception made for the marine sediments was the microscopic identification of the origin of the sediment grains (skeletal grains vs. grains originating from the cliff material).

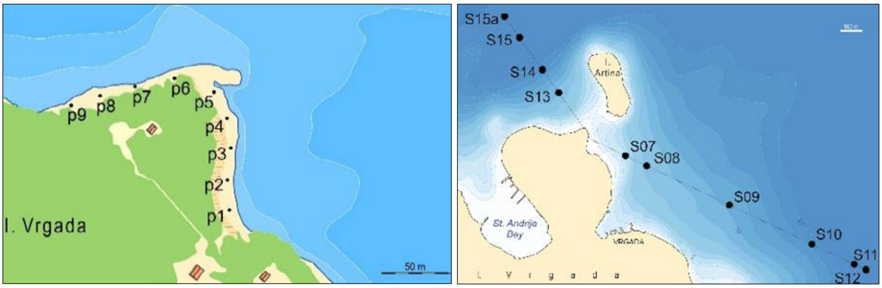

Figure 2 – Location map of beach sediment sampling (left) and marine sediment sampling (right; slightly modified after [13].

Results

Figure 3 summarises the main erosion events that occurred during the monitoring period, namely two massive rockfalls. They occurred at the site where a deep crack had previously formed at the edge of the cliff. The first massive rockfall occurred between October 2022 and April 2023, when only a small part of the detached cliff block collapsed. The second, larger rockfall occurred at the end of the May 2023 or the very beginning of June 2023 (Figure 3) when most of the detached rock mass fell. It is assumed that rockfalls were triggered by higher humidity during winter and intensive rains in May. After both rockfalls, the rock mass partially crushed and the finer sediment material were washed away by both rain and incoming waves.

All beach sediment samples analysed were characterized as sands: On the eastern side of the beach, slightly gravelly sands predominated, while the rest were pure sands. On the north-western side of the beach, half of the samples were slightly gravelly sands and the other half were sands (Table 1). The mean and median grain size showed three cycles of grain coarsening starting from sample P1 to sample P9, both varying between 186÷292 μm and between 185÷312 μm, respectively. The carbonate content varied between 18 and 25 %, with a slight increase from eastern to the north-western part of the beach.

The percentage of heavy minerals in the analysed samples ranged from 6.03 to 51.86 % on the eastern side of the beach, with an average of 24.35 %. The north-western side of the beach contained a much lower percentage of heavy minerals: between 2.43 and 11.03 %, with an average of 6.17 % (Table 1.). A total of twelve species of transparent heavy minerals were identified: garnets zircon, rutile, titanite, tourmaline, chromite, epidote, clinozoisite, pyroxenes - mainly augite, amphibole, chlorite and kyanite. The proportions of all three groups of heavy minerals (opaque, phyllosilicates and transparent) change from east toward west.

The proportions of opaque minerals, phyllosilicates and transparent heavy minerals vary from P1 to P9. Opaque minerals predominate in all samples, but their proportion decreases slightly towards the west. A similar pattern was observed in the phyllosilicates, while the transparent heavy minerals showed an opposite trend and their proportion increased from P1 to P9. Heavy minerals whose density exceeds 4.5 g/cm^3 (rutile, zircon and chromite) showed decreasing trend from P1 to P9, while the remaining minerals with a density between 2.95 and 3.9 g/cm^3 show an opposite trend.

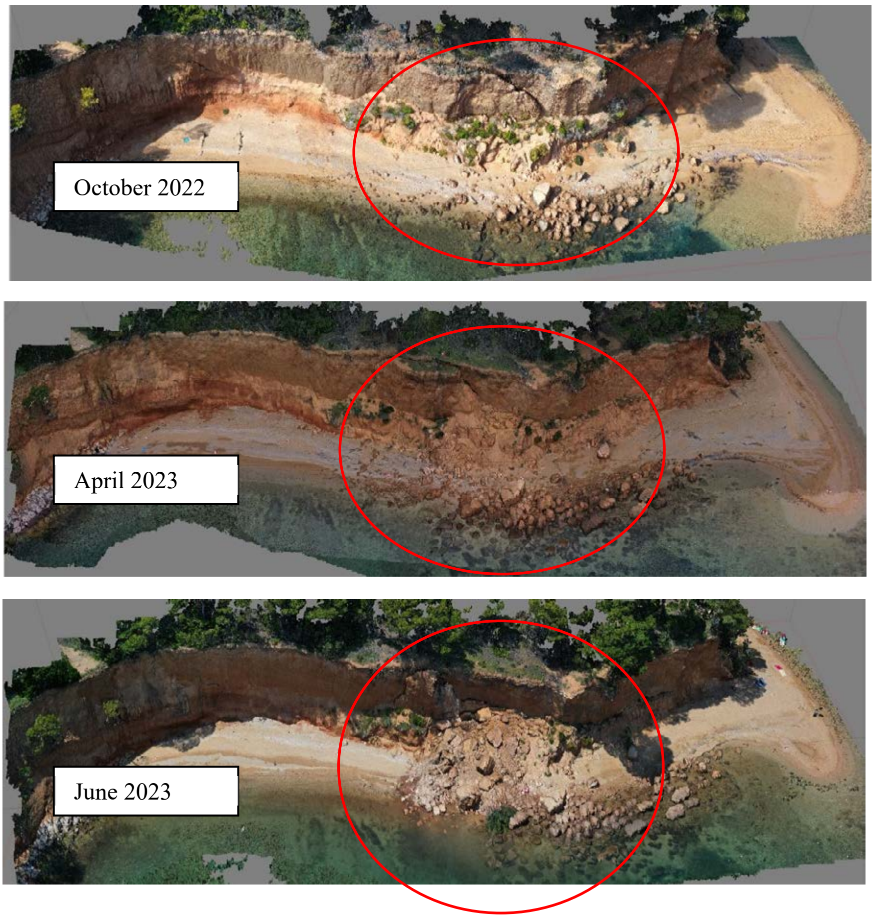

Figure 3 – Digital models of the Vrgada cliff with rockfalls that occurred between October 2022 (upper), April 2023 (middle) and June 2023 (lower).

According to previously published data by [13], the marine surface sediments sampled off the eastern part of the beach (profile S07-S12; Figure 2) are a coarse-grained and highly carbonaceous material, with part of the carbonate fraction and coarse grain sizes originating from the cliff material. In contrast, material deposited off the north-western part of the beach (profile S13-S15a, Figure 2) was finer, contained less carbonates and more quartz.

Table 1 – General characteristics of the beach sediments P1-P9. Legend: S – sand; sgS – slightly gravelly sand; Mz – mean size; Md – median; Carb. – carbonates; HM – heavy minerals; OP – opaque; Phy – phyllosilicates; Tra – transparent.

Sample:	Sediment type	Mz (μm)	Md (μm)	Carb. (%):	HM (%)	OP (%)	Phy (%)	Tra (%)
P1	S	186.6	185.1	18.4	51.86	52	13	35
P2	sgS	235.1	226.2	22.8	6.03	50	7	43
P3	sgS	254.5	251.2	21.5	22.49	57	5	38
P4	sgS	186.6	185.1	20.5	22.57	55	2	43
P5	S	217.1	205.9	24.9	18.78	63	2	40
P6	sgS	248.4	230.1	20.7	8.58	49	2	49
P7	S	206.7	194.6	25.2	2.62	52	3	45
P8	sgS	255.8	232.0	24.2	11.03	51	3	46
P9	S	292.1	312.2	21.4	2.43	49	4	47

Discussion

The Vrgada cliff is one of the rare examples of soft rock cliffs on the Croatian coast. It was developed in Pleistocene aeolian-alluvial deposits, i.e. partially reworked loess [1]. The cliff is L-shaped with a sandy beach at the immediate front (Figure 4). The north-western side of the cliff is less steep and covered with pine forest and is influenced by the mild NW wind waves that occur mainly in summer. The eastern side of the cliff is vertical and bare and exposed to two dominant wind waves: SE wind waves generated by the Scirocco and NE Bora wind waves. As the Scirocco has a larger fetch, its waves are thought to have a dominant influence on the eastern section of the beach. However, according to the locals, the NE Bora wind itself can create a hammer effect directly on the cliff face due to its gales. Digital elevation models from October 2022 (Figure 3) showed debris on the beach immediately in front of the steep part of the cliff, indicating past rockfalls. Many of the fallen blocks are of metric dimension. Another rockfall occurred between October 2022 and April 2023 (Figure 3) when a semi-detached block collapsed. The predisposition of the rockfall was a deep crack (Figure 5). The crack was discovered during the initial fieldwork in 2016 and has slowly widened since then. Most of the semi-detached rock mass was only held to the cliff by strong root branches of Aleppo pine (Figure 5). Considering that the Mediterranean winters are characterized by more precipitation compared to the warm seasons, it is likely that more frequent rain could trigger this rockfall. This assumption was confirmed in the case of the second rockfall that occurred between April and June 2023 (Figure 3). According to the Croatian Meteorological and Hydrological Service, precipitation for May 2023 increased just before the monitoring in early June. During the second rockfall, a large part of the semi-detached rock mass collapsed and was subsequently washed away by rain and waves. The distribution of coarse-grained material on the beach and prevailing wind waves indicate that the long-shore transport starts at the eastern part of the beach and ends at the north-western part. To test this hypothesis, beach and marine sediments were further studied.

Figure 4 – Aerial photograph of L shaped beach in front of the Vrgada cliff.

Figure 5 – Semi-detached part of the cliff with visible crack and root branches of Aleppo pine.

During the fieldwork, obvious differences in the coarseness of the beach sediment became apparent: the eastern part contained much more gravelly material derived from cliff-collapsed material (e.g. blocks, rhizocretions, carbonate crusts, etc. [1]; Figure 4). However, the beach sediment samples analysed in this work were classified as sands and slightly gravelly sands in both beach sections, showing a coarsening rather than a refinement of the sediment toward the west. Nevertheless, such results can be explained by the sampling strategy, which was designed to perform an accurate heavy mineral analysis: Coarse-grained carbonate gravels, pebbles and blocks were avoided during sampling. The second part of the explanation comes from [8]: Coarse-grained sediments tend to contain light minerals such as quartz. Due to their low density, they are much easier to resuspend, while their large surface area is exposed to the resuspending force. Such behaviour could lead to a more effective transport of somewhat coarser material, as found at the two Vrgada beaches. However, the grain size analysis should be repeated in the future to include coarse-grained beach material.

Although that grain size analysis itself did not provide expected results, these were obtained by the heavy mineral analysis. As shown in Table 1, the highest proportion of heavy minerals was found in sample P1. In general, four times the average amount of all heavy minerals was found in the eastern part of the beach (24.35 %), compared to 6.17 % in the north-western part of the beach. This is probably the result of the continuous erosion of the cliff material. Opaque heavy minerals generally had the highest proportion, followed by transparent heavy minerals and less abundant phyllosilicates (Table 1). The highest abundance of opaque minerals is probably due to their abundance in rock cliff material [1]. Their decreasing trend from the eastern to the north-western part of the beach reflects the possibility that they include minerals whose density, exceeds 4.5 g/cm^3 (e.g. rutile, zircon and chromite). Due to their high density, they have remained in the eastern part of the beach. The remaining heavy minerals with a density between 2.95 and 3.9 g/cm^3 show an opposite trend of increasing amounts from the eastern to the north-western beach. The proportions of transparent heavy minerals increase in a north-westerly direction, as their density is lower than that of the opaque minerals. Finally, the phyllosilicates show a decreasing trend in a north-westerly direction. This distribution could be due to the fact that the eastern part of the cliff erodes faster than the gently sloping north-western part, where the vegetation covers further reduces the erosion rate. Furthermore, once resuspended, phyllosilicates are transported over longer distances [14], and in this case perhaps even further out to the sea. In general, the transport of all heavy minerals is directly related to their density and size, and it can be concluded that they exhibit a general long-shore drift from the eastern to the north-western part of the beach.

As for the marine sediments, the sediments collected off the eastern part of the beach contain more carbonates and are generally coarse-grained (gravelly sands and gravelly muddy sands according to [13]. In particular, the sediment sampled near the beach reflects some of the main characteristics of beach sediment and contains rhizocretion, carbonate crusts and other grains eroded from the cliff in coarse fractions. Sediment samples collected in deeper areas are a typical eastern Adriatic sediment with a high proportion of biogenous carbonate material. On the other hand, marine sediments sampled in front of the north-western part of the beach are generally fine-grained (gravelly muddy sand and gravelly muds according to [13], and contain more non-carbonate grains, of which quartz dominates. Such finding is consistent with the mechanisms of transport of light and heavy minerals described above. This generally fine-grained sediment can easily be withdrawn into the deeper sea and deposited on the seafloor.

It is generally well known that the seagrass *Posidonia oceanica* does not tolerate significant input of terrigenous sediment [4]. The fact that *Posidonia oceanica* meadow is found at shallower depths off the eastern part of the beach indicates that no significant amount of terrigenous material enters the sea at the sites where continuous cliff erosion occurs. Instead, eroded cliff material is transported by the long-shore drift from the eastern to the northwestern side and ends up in the sea, in places where *Posidonia oceanica* was sparse.

Finally, the ongoing erosion of the Vrgada cliff may jeopardise anthropogenic infrastructure and change the land use on the cliff top in the future. On the other hand, the eroded material may affect the waterways and related nautical activities.

Conclusions

The soft-rock coastal cliff on the Vrgada island is susceptible to constant erosion. Successive digital models have shown that the predominant slope processes on the cliff are rockfalls. The eroded material is reworked and partially washed away by rain and waves. As a result, an L-shaped beach has formed. The prevailing waves are generated by the Scirocco (SE) wind, which causes a long-shore transport of eroded material from the eastern to the north-western part of the beach. The results of the heavy mineral analysis, partially grain size analysis and carbonate content in the beach sediment confirmed the longshore transport, while the characteristics of the marine sediments deposited in front of the both beach sections further confirmed the long-shore transport. It is expected that the local input of terrigenous sediment may affect the distribution of seagrass meadows distribution, as well as the waterways. The erosion of the Vrgada cliff poses a threat to anthropogenic infrastructure in the future and could alter the island's coastline.

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A MULTISCALE ANALYSIS OF THE MORPHOLOGICAL SETTING ALONG THE SUSCEPTIBLE COASTAL AREA OF THE AGRI RIVER (SOUTHERN ITALY)

Angela Rizzo, Giuseppe Corrado, Gianluigi Di Paola, Antonio Minervino Amodio, Dario Gioia

Abstract: Assessment of coastal vulnerability to physical and anthropic processes is a crucial step in coastal risk management, especially in climate change scenarios characterized by sea level rise and increasing human pressure. The application of geomorphological-based indices is a consolidated approach to estimate the degree of vulnerability to erosion processes of low-relief coasts at a regional/wide scale. Such a method is based on the combination of physical variables such as shoreline changes, dune and beach geometry, vegetation, and coastal infrastructures, which are statistically or arbitrarily ranked to extract a vulnerability classification. Recent advances in the availability of UAV platforms with higher performance in terms of flight duration, sensor availability, and mapping resolution provide a unique opportunity for a comparison between high-resolution DEMs and the results that can be obtained from the application of a Coastal Index (CI). In this study, short- and medium-term comparison (i.e. about ten years) of high-resolution DEMs (derived by LiDAR) was performed in one of the sectors of the Ionian coastal belt, providing new insights about the geomorphological evolution of a highly vulnerable sector along a retreating coast. Such a comparison was tested along a sector of the coastal areas of the Basilicata region, southern Italy, that includes the Agri River mouth. The study area is featured by a strong human impact and environmental factors that have promoted in the last years the occurrence of remarkable shoreline retreat and coastal erosion.

Keywords: Coastal erosion, susceptibility index, monitoring techniques, Ionian coast

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Introduction

Assessment of coastal vulnerability to physical and anthropogenic processes is a crucial step in coastal risk management, especially in scenarios promoted by sea level rise, climate change, and increasing human pressure [14, 24, 29]. The application of geomorphological susceptibility indices is a consolidated approach to estimate the proneness to erosion processes of low-lying coasts at the regional/wide scale [28]. Such a method is based on the combination of physical variables such as shoreline changes, dune and beach geometry, vegetation, and coastal infrastructures, which are statistically or arbitrarily ranked to extract a coastal vulnerability classification [15, 22].

Recent advances in the availability of Unmanned aerial systems (UAS) platforms with higher performance in terms of flight duration, sensor availability, and mapping resolution provide a unique opportunity to compare high-resolution point clouds or DEMs with the results that are obtained from the application of a Coastal Index (CI) [3]. UAS technology has recently advanced, allowing for the development of an alternative coastal monitoring method that effectively captures the spatial and temporal requirements across a wide variety of environmental applications [9, 16, 25, 27].

In this study, a methodological approach aimed at the reconstruction of the short-term evolution of a highly vulnerable coastal sector based on the integrated analysis of CI and multitemporal LIDAR surveys is proposed. The analysis has been tested along the Ionion sector of the Basilicata region, southern Italy (Figure 1) [8, 11]. In this sector, several environmental factors as well as a strong human impact have favoured severe shoreline retreat and coastal erosion [5]. The present-day shore is characterized by a low-gradient sandy beach that is limited landward by several diachronic dune ridges. Fine marshy deposits can be observed between these different generations of dunes. The application of an already tested coastal susceptibility index [1, 20] has allowed the identification of erosion hot-spots (i.e., the areas that can be considered more susceptible to erosion) along an approximately 7 km coastal strip that includes the Agri river mouth. More detailed investigations based on the exploitation of UAS derived-data were performed for the hot-spot areas. In particular, short-term comparison (i.e., about ten years) of high-resolution LIDAR DEMs was performed. To this aim, two types of LiDAR-derived data were used: 1) raw point clouds obtained from a LiDAR survey from aircraft carried out in 2013 at the regional scale; 2) point clouds obtained from a UAS survey carried out for this study in December 2023 with a LiDAR sensor. The comparison of the two high-resolution surveys allowed us to observe and quantify both the 2-D and volumetric changes occurring in the hot-spot areas, previously identified by the application of the coastal susceptibility index. Our data can be useful to 1) verify the usefulness of the methodology for the precise and effective delineation of coastal areas at risk of erosion due to recent sea levels; 2) provide valuable information regarding the degree of coastal susceptibility along the coasts.

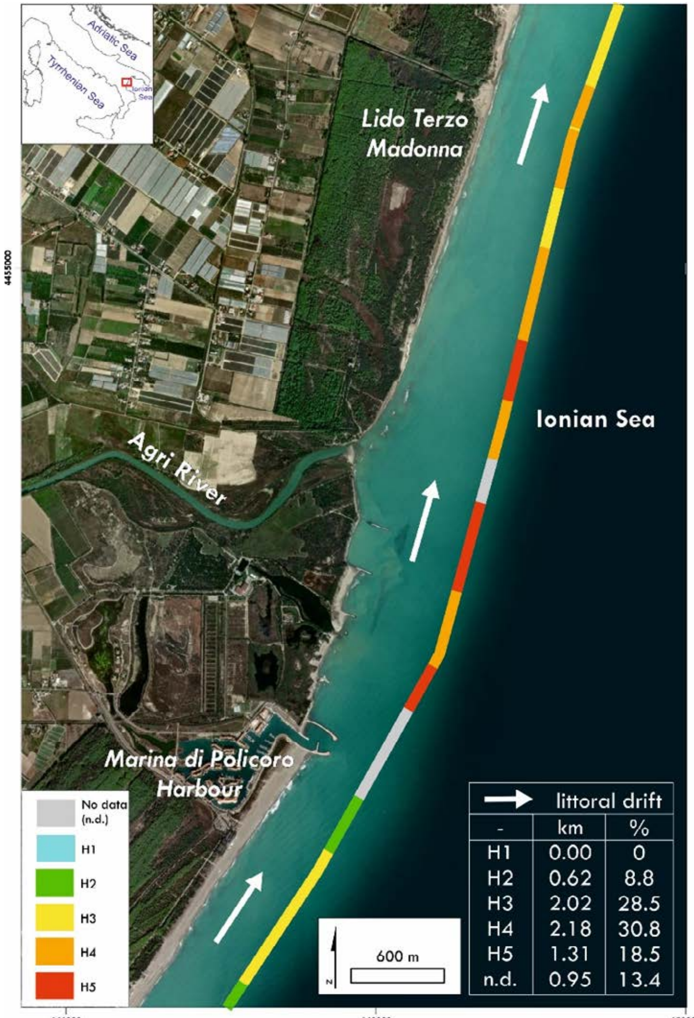

Figure 1 – Geographical location of the study area and graphical representation of the CESI results. On the right corner, quantitative CESI results are also provided, expressed both as kilometers and as percentage values.

Study area

The study area is located along the Ionian coastal belt of the Basilicata region, southern Italy (Fig. 1). It belongs to the southernmost and youngest outcropping sector of the Bradano Foredeep, which experimented a progressive stage of emersion since the Middle Pleistocene [7, 11, 12] as a consequence of the interplay between tectonic uplift and eustatic sea-level cycles. Moreover, it is characterized by a continental shelf developed for about 3÷4 km with a dip lower than 1°, and the break is located at a depth of about 40÷50 m b.s.l. [23].

The landscape is dominated by the presence of several well-preserved orders of marine terraces, which are deeply incised by a fluvial net with an angular pattern [3, 6, 10, 26]. The present-day shore is featured by a low-gradient sandy beach that is limited landward by several meters-thick dunes, striking mainly parallel to the shoreline [8, 18, 23]. Fine marshy deposits accumulated between these different generations of dunes. Lower altitudes sectors of the Metaponto coastal plain were characterized by wide outcrops of limno-palustrine deposits, which have been affected by land reclamation during the first decades of the 1900s. The plain is now featured by sandy and silty meandering fluvial systems with several artificial channels. These areas of the coastal plain are still affected by occasional flooding events during extreme rainfall events [18].

The maximum fetch reaches about 500 km and derives from the SE-oriented quadrant and the surface circulation is anticyclonic in the winter season while, in the summer season, it is cyclonic, according to the application of the Marine Rapid Environmental Assessment (MREA) method [19]. This opposite circulation pattern is probably connected to the different Western Adriatic Coastal Current [13, 19]. Anemological climate acquired in a wind station located in the proximity of the Agri River mouth (Terra Montonata station, ARPAB, Agenzia Regionale per la Protezione dell'Ambiente in Basilicata) identified average wind speed values of about 9 m/s, with dominant SE winds. Such data, coupled with the sedimentological and mineralogical studies carried out on a wider coastal sector, allow the identification of a main direction of sediment transport (littoral drift) toward NE [2, 23].

In 2006 and 2012, two inland tourist ports, each protected by jetties, were built on both the left sides of Agri and Basento river mouths. Starting from their construction, the breakwaters modified the sediment distribution by the longshore currents, principally directed from SW to NE, accentuating the deposition in the southernmost part and increasing the erosion in the other part of the coast [17]. Such disturbance in the sediment distribution affects also other coastal areas, near the mouths of the Basento and Bradano rivers, due to the construction of two inland tourist ports [17].

Materials and Methods

The proposed multiscale procedure is based on the exploitation of an already available coastal susceptibility index [1, 20], i.e. the Coastal Erosion Susceptibility Index (CESI), which is here adopted to analyze the proneness to erosion of the littoral sector extending along the Agri River month (7 km long). The applied index is a linear combination of weighted variables covering site-specific geomorpho-dynamic aspects. CESI results are then ranked into five classes ranging from null/very low susceptibility (Class H1) to very high susceptibility (Class H5). Based on CESI results, erosion hot-spot areas were identified. In these areas, a LiDAR survey was performed using a Dji Zenmuse L1 3-echo laser scanner, equipped with a GNSS RTK positioning system, used as a payload on a DJI Matrice 300 drone. LiDAR acquisition covered an area of about 60 ha. Flights were carried out at 120 m AGL, at a constant speed of 3.5 m/s, in a double acquisition grid pattern.

The LiDAR used has the following specifications: (i) 3-echo, (ii) 70° of FOV (Field of View), and (iii) 480 000 measurements per second. The LiDAR data provide a DEM of the study area and an orthophoto. The latter is provided by the coloring of the point cloud thanks to an RGB camera. DEMs relative to the years 2023 (created for this study) and 2013 (provided by the regional authorities) are used to extract 250 m spaced transects and to assess the main morphological variations that occurred in the last 10 years in the investigated coastal stretch. These analyses have been performed exploiting GIS-based tools (in particular, the QGIS "profile tool" was used for the transect extraction).

Results and Discussion

The results of the CESI application are graphically shown in Figure 1, from which it emerges that the investigated coastal sector is characterized by a susceptibility level ranging from "low" – in green, to "very high" – in red. Grey sectors identify areas in which the CSEI values are not available due to the lack of suitable data.

The quantitative analysis highlighted that less than 10 % of the investigated area has a low susceptibility level and that approximately 28 % of the investigated area has a medium level of susceptibility. High and very high susceptibility levels characterize 30.8 % and 18.5 % of the investigated area, respectively. Finally, a coastal stretch 1 km long was excluded from the CESI calculation due to the presence of a permanent anthropogenic structure (i.e., the Marina di Policoro harbor) and the Agri River mouth. CESI results allowed the identification of hot-spot erosion areas to be investigated in greater detail, which occupy a surface of 3.5 km (almost 50 % of the total investigated area). They are located mostly around the river mouth and towards the northernmost part of the study area. Conversely, the low susceptibility sector is located on the breakwater pier, highlighting the influence of the hard structure on the overall coastal dynamic. Starting from the point clouds derived by the photogrammetric acquisition performed in 2013 (aircraft) and 2023 (UAV), orthophotos and DEMs were generated with a resolution of 10 cm (Figure 2).

From the DEMs, six topographical profiles (T1-T6) were extracted and analyzed (Figure 3). In detail, along each profile, the following morphological parameters were evaluated for both investigated years (2013 and 2023): height of the ordinary berm, width of the backshore, mean slope of the backshore, and slope of the foreshore. The estimated values are synthesized in Figure 4. For T2, these parameters were calculated only for the year 2013, since the beach has been completely replaced by a hard structure. For what concern the slope of the backshore, it increased in the case of T1 (passing from 1.4 % to 7 %) while in the remaining profiles (T4, T5, and T6) it decreased by 39.6 %, 91.7 %, and 100 %. In the case of the foreshore, the slope is decreased in all the profiles, except for the T6 profile, for which the backshore slope has increased by 240.8 %.

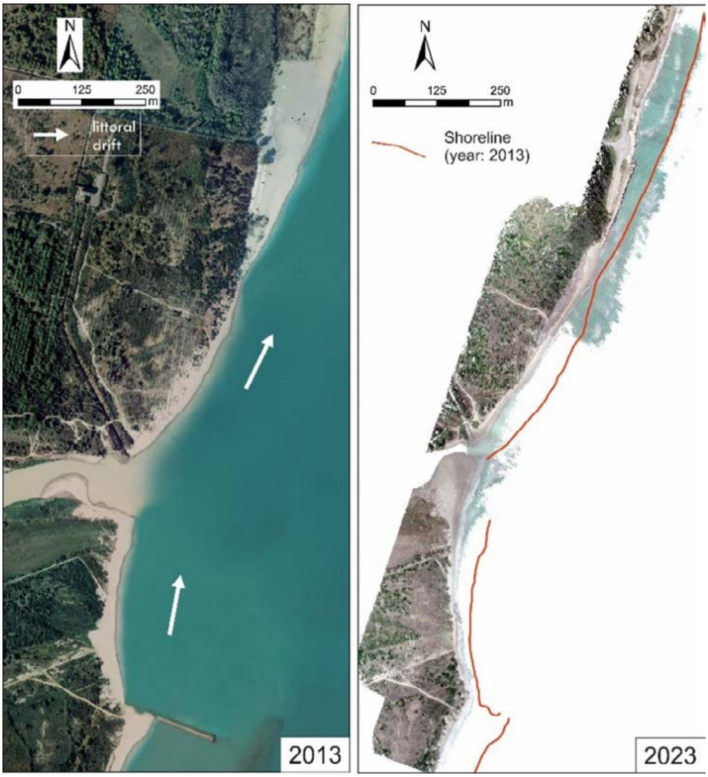

Figure 2 – Comparison between the two ortophotos of the surveyed area. The shoreline derived from the 2013 survey was drawn on the 2023 image to highlight the severe coastal retreat that occurred in the last 10 years.

Figure 3 – Location of the topographical profiles (T1-T6) extracted from DEMs and differences in topographical height estimated from the comparison between DEMs relative to the years 2023 and 2013.

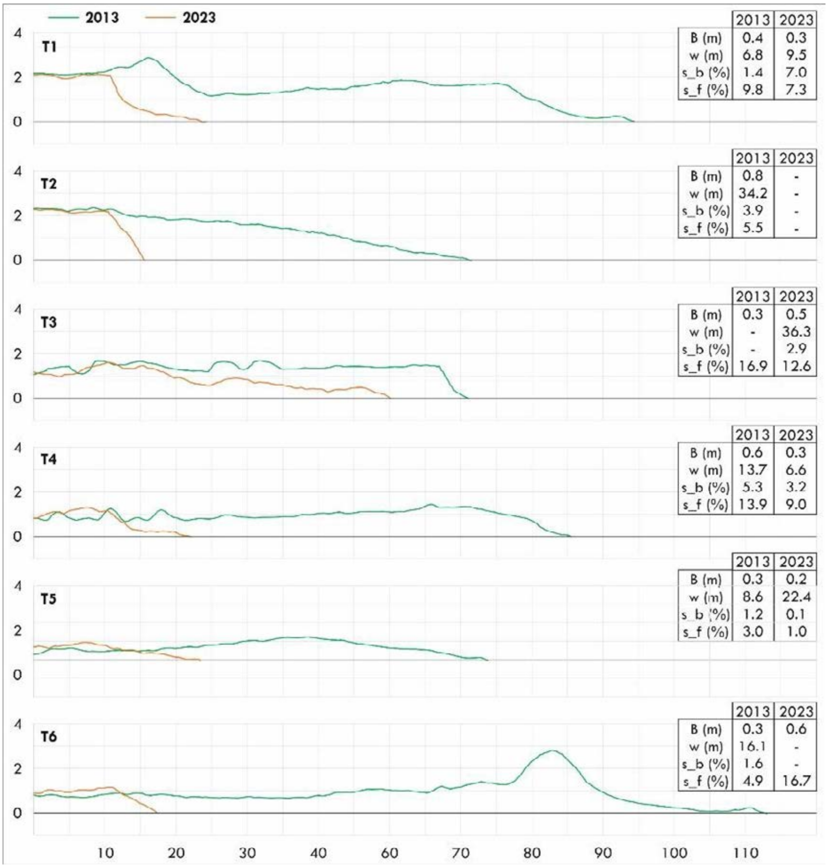

Figure 4 – Beach topographical profiles (T1-T6) along the study area. In the tables, the values of the main morphological parameters calculated along each profile are indicated. Legend: B (m) = berm height, w = width beach; s_b (%) = backshore slope, s_f (%) = foreshore slope.

Despite the general erosion trend that characterizes the investigated coastal sector, profiles T1, T3, and showed an increase in backshore width, with values of 2.7 m, 36.3 m, and 13.8 m, respectively. This latter aspect is related to the substantial naturalness of these areas, with systems free to move inland.

Overall, the qualitative analysis of the T1–T6 profiles (Figure 4) highlights the following trends:

- T1: the sector shows a strong coastal retreat, with the total damage of the dune system which is nowadays completely absent;
- T2: the beach has been completely eroded and an adherent structure (revetment) has been placed to protect the inland coastal zone;
- T3: the sector shows a prevailing coastal retreat, with the formation of a beach probably as a consequence of the dune demolition;
- T4: the sector shows strong coastal retreat with rates up to 5 m/year;

- T5: the sector shows complete erosion that affects also the dune system; T6: the sector shows a complete beach erosion with has caused the demolition; of the groin clearly recognizable on the 2013 orthophoto.

The DEM of Difference (DoD, see Figure 3) between the two high-resolution DEMs (with a spatial resolution of 0.1 m) provides additional quantitative information on the short-term geomorphological evolution of the study area. Quantitative analysis of the DoD allowed us to quantitatively detect the remarkable volume changes that occurred along the surveyed coast. Negative and positive values of the DoD map show erosion and deposition, respectively (Figure 5). Values ranging from -0.1 to 0.1 m were considered as thresholds for the stable areas. Statistical analysis of the pixel distribution of the DoD map highlights the large erosion trend of the study area, with a net eroded volume of about 250 000 m^3 (Figure 5b). By considering the 2013 beach as a reference surface, the eroded volume is about 29 000 m^3 (Figure 5c).

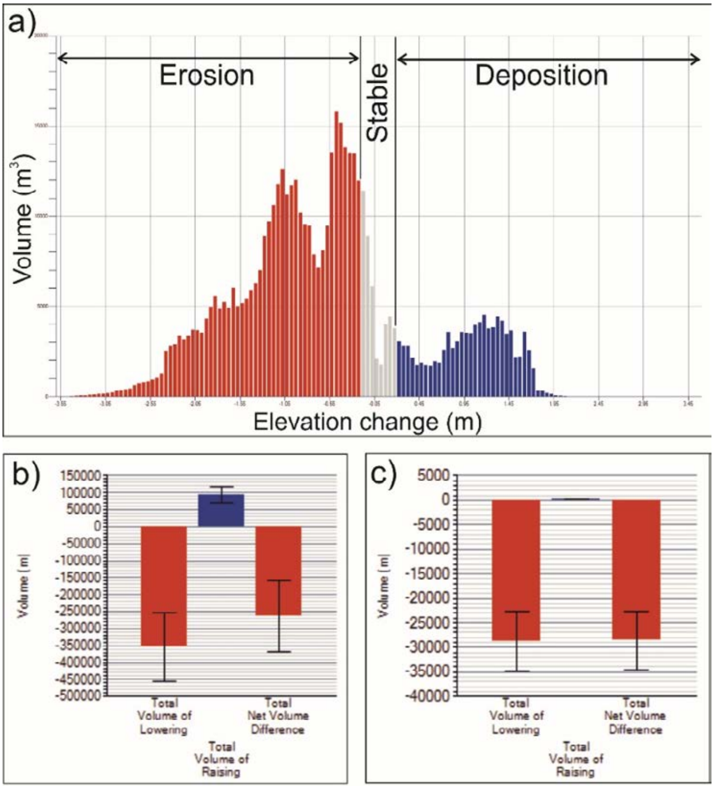

Figure 5 – Graphs showing the volumetric changes estimated by DoD mapderived from the multitemporal analysis of the study area. a) Histogram of the volumetric changes estimated by the statistical analysis of the DoD map; b) plot showing the positive (deposition) and negative (erosion) volumes for the entire area; c) plot depicting the volumetric change for the beach sector reconstructed from the 2013 survey.

These changes can either become part of a persistent trend or simply show reversible fluctuations. Furthermore, as shown in Figure 2, the availability of high-resolution topographic data is crucial for characterizing and monitoring the coastline and also for assessing coastal flooding scenarios. To assess morphological variations at a lower temporal scale (i.e., months), further activities will be focused on performing UAV surveys with a lower temporal interval and considering the occurrence of extreme weather events (i.e., storm surges). In this way, the comparison will be based on DEM acquired with the same survey's parameters, ensuring a higher spatial accuracy.

Conclusion

In this paper, a multiscale approach aimed at the reconstruction of the short medium-term evolution of a highly vulnerable coastal sector based on the integrated analysis of CI and multitemporal LIDAR surveys was tested. Such a comparison was performed along the Ionian coastal sector of the Basilicata, southern Italy, which includes the Agri River mouth where several environmental factors as well as a strong human impact have favoured the severe occurrence of shoreline retreat and coastal erosion.

According to the obtained results, 30.8 % and 18.5 % of the investigated areas are characterized by high and very high susceptibility levels, respectively. Conversely, the low susceptibility sector is located on the breakwater pier, highlighting the influence of the hard structure on the overall coastal dynamic. Despite the general erosion trend that characterizes the investigated coastal sector, some profiles showed an increase in the backshore width of up to 36 meters (T5). This latter aspect is related to the substantial naturalness of these areas, with systems able to move inland.

Quantitative analysis of the DoD allowed us to provide an overall quantification of the volume changes occurring along the surveyed coastal stretch. This aspect highlights the large erosion trend of the study area, with a net eroded volume of about 250 000 m^3. By considering the 2013 beach as a reference surface, the eroded volume reached a value of about 29 000 m^3.

This study shows how susceptibility indices are very useful for the qualitative identification of areas subjected to main changes in beach systems, but they need to be integrated by high-resolution and repeated monitoring campaigns over large areas, which can represent effective data to both a finer reconstruction of the geomorphological evolution of wide sectors of vulnerable coasts. The obtained results demonstrate that the susceptibility to erosion can experience significant short-medium term changes, even from year to year, as also evidenced by other studies conducted in similar coastal contexts [9,16]. Finally, in compliance with the guidelines proposed for the integrated geo-environmental characterization of coastal sites [21], this study highlighted the remarkable role of high-resolution surveys in coastal monitoring programs.

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SHORELINE DETECTION BY APPLYING SEMIAUTOMATIC ALGORITHMS FOR HYPERSPECTRAL AND MULTISPECTRAL SATELLITE IMAGERY ON THE BEACHES OF THE GULF OF ORISTANO (SARDINIA, ITALY)

Sabrina Terracciano, Juan Montes-Pérez, Riccardo Brunetta, Paulo Cabrita, Enrico Duo, Paolo Ciavola, Clara Armaroli

Abstract: Coastal areas are influenced by natural processes and human activities and require effective monitoring tools to understand their dynamic evolution. This study utilizes satellite imagery and semi-automatic shoreline extraction algorithms (CoastSat and SAET) to assess coastal erosion in the Gulf of Oristano over long-term and short-term periods. The algorithms' performance was validated using PRISMA and Sentinel-2 imagery, alongside RTK-GNSS surveys acquired during ASI OVERSEE project fieldwork. The field site beaches vary in exposure due to their positions, and their morphologies are influenced by the presence of *Posidonia oceanica* banquettes. A one-year analysis focused on Arborea Beach, where periodic Posidonia banquettes affect the accuracy of Satellite-Derived Shorelines (SDSs). The study shows the beach's susceptibility to storm surges, evidenced by significant erosion after a major storm in March. Despite algorithmic limitations, automated shoreline extraction allows efficient temporal analysis. This research evidences the role of advanced algorithms in precise coastal monitoring, offering crucial insights into erosion dynamics and supporting effective mitigation strategies.

Keywords: Coastal dynamics; CoastSat; SAET

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Sabrina Terracciano, Juan Montes-Pérez, Riccardo Brunetta, Paulo Cabrita, Enrico Duo, Paolo Ciavola, Clara Armaroli, *Shoreline detection by applying semiautomatic algorithms for hyperspectral and multispectral satellite imagery on the beaches of the Gulf of Oristano (Sardinia, Italy)*, pp. 815-827, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.71

Introduction

The influence of storm events can generate erosion and modify the morphology of beaches, resulting in sediment loss and coastal damage [1]. Anthropogenic impact on coastal areas and the reduction of return periods of extreme events due to climate change, make it necessary to monitor these environments to predict future consequences [2].

Traditional coastal monitoring techniques often have limitations, such as small study areas or low temporal resolution. To address these issues, the use of freely available optical satellite imagery with planetary coverage and high revisit frequency is increasingly being utilized. The development of algorithms for shoreline extraction has significantly enhanced and streamlined the study of coastal systems. These advancements enable automated temporal analysis over periods ranging from a few days to several years [3].

Beach erosion can be classified into two main types. The first type is permanent shoreline retreat, which is driven by factors such as rising mean sea levels and negative coastal sedimentary budgets, leading to the inland migration or submersion of beaches. The second type is temporary erosion, which results from storm surges and wave action. Although this form of erosion may not always cause long lasting shoreline retreat, it can still be highly destructive [4]. Even though some coastal systems adapted to the impact of extreme events without showing chronic retreat, the increasing frequency of storm events continues to pose significant challenges [5].

The aim of this study is to analyse the erosion impact of storms events, evaluate the effectiveness of satellite imagery and shoreline extraction algorithms in monitoring these changes in order to better understand and mitigate the effects of permanent and temporary beach erosion.

Materials and Methods

This study is focused on the Gulf of Oristano, a semi-enclosed embayment located on the western coast of Sardinia, Italy. The Gulf of Oristano covers an area of approximately 150 km^2 with an average depth of about 15 m and with a maximum depth of around 25 meters [6]. The coastline of the Gulf of Oristano is characterized for the presence of long stretches of sandy beaches. The back shore is predominantly occupied by extensive salt-marsh systems and several coastal lagoons (Figure 1).

The meteo-marine conditions in the Gulf of Oristano are influenced by three predominant wind regimes. The northwest winds, known locally as the Mistral, are the most powerful. Additionally, winds from the southwest (Libeccio), and from the southeast (Sirocco), also affect the area. Despite the dynamic wind patterns, the tidal range is limited, approximately 20 cm.

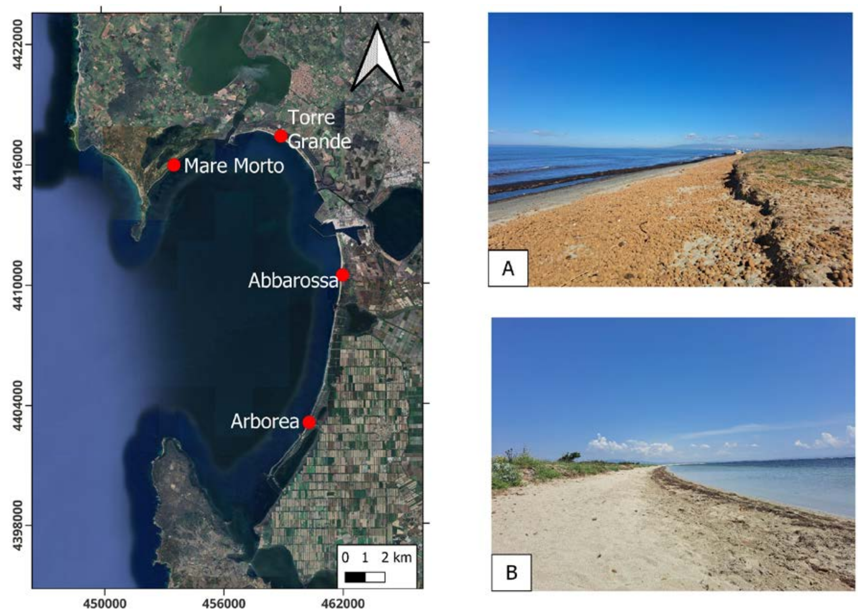

Figure 1 – Study area: A) Arborea beach; B) Mare Morto beach.

An initial 20-year study (2002-2022) was conducted. This study involved extracting the shoreline for the entire Gulf of Oristano using the CoastSat algorithm [7] for multispectral images in order to identify erosional trends. Landsat 7 satellite images were used due to their availability from the 2000s and their spatial resolution of 15 meters. The decision to use the CoastSat algorithm for long-term analysis was based on its ability to perform extensive temporal analyses quickly and automatically. Once the SDS dataset was obtained, a preliminary analysis of the principal trends over 20 years of shoreline data was conducted using CoastSat post-processing tools.

Subsequently, a 3-year study (2022-2024) was conducted and the SDS extraction for the entire Gulf of Oristano was performed using the SAET algorithm [8] with Sentinel-2 satellite imagery. The algorithm is specifically developed for storm events and ensures better accuracy under these conditions.

Once the second SDS dataset was obtained, the Digital Shoreline Analysis System (DSAS) tool in ArcMap was employed to analyse the erosion trends. This tool utilizes multiple statistical methods to establish the relationship between the shorelines and requires certain parameters to be set by the operator [9]. Initially, an offshore baseline was edited parallel to the shorelines. Subsequently, transect perpendicular to the baseline spaced 100 m were generated. Finally, various statistical analyses were applied to the points where the transects intersect the shorelines, following the methodology outlined by Himmelstoss et al. [9]: Net Shoreline Movement (NSM), the Shoreline Change Envelope (SCE), the End Point Rate (EPR) and the Linear Regression Rate (LRR). The NSM corresponds to the distance (m) between the oldest and the most recent shoreline, the SCE represent the value of the distance from the closest intersection from the baseline and the farthest, while EPR is the ratio of the NSM to the time between the oldest and most recent shoreline [10]. Finally, the Linear Regression Rate (LRR) represents the rate of change in meters per year. It is determined by the slope of the regression line, which is calculated based on the intersection points of time and distance from the baseline.

Further analyses on a smaller scale were focused on Arborea beach, located in the southern part of the Gulf of Oristano. This dissipative beach which faces the northwest and is exposed to the storm events driven by the Mistral winds. Its primary characteristic is the presence of *Posidonia oceanica* banquettes, *Posidonia oceanica* is a Mediterranean seagrass, which accumulates naturally on the beach [11] with higher frequency along the shore and in larger quantities in the southern part near the jetty.

Importantly, Posidonia deposits are left untouched by human activities, allowing natural processes to occur uninterrupted [12]. This beach has undergone several human-induced changes over the years. A road has been constructed across the dune area and walking paths have been established on the dunes. Additionally, there is a World War II military bunker present on the beach.

The first analysis performed on Arborea beach was the error analysis, through shoreline extraction using three different algorithms: two for multispectral images (CoastSat and SAET) and one for hyperspectral images (HyperSho), employing the profile method as the shoreline extraction technique [13]. To ensure comparable results and highlight the efficacy of SAET algorithm using various water indices, the AWEIsh index was employed in extracting shoreline positions. This index is particularly effective in identifying the sand-water boundary under conditions with dark elements, such as shadows [14]. Additionally, this index has demonstrated good performance and accuracy in the presence of *Posidonia oceanica* on Arborea Beach [15]. The accuracy of the extraction was evaluated through the comparison with in-situ data. Average distances were calculated using ArcGIS tools by measuring the distance from the points of the Satellite-Derived Shorelines (SDS) to the line of in-situ data. The instant shoreline (defined as the boundary between water and sand) was acquired with RTK-GNSS during the campaigns for the OVERSEE project on 18/09/2022, 23/05/2023, and 10/10/2023 by continuous measurement with an acquisition time of 1 second.

Finally, a one-year analysis was conducted on Arborea Beach to examine in detail the impact of storms, as well as erosional and accretional trends. The year analysed was 2023 and to ensure that the analysis was conducted using an initial condition of seasonal stability, the shoreline from 13 September 2022 was chosen as the reference shoreline [3]. SAET algorithm was selected as the preferred extraction method due to its better accuracy revealed in the error analysis. Regarding the HyperSho algorithm for hyperspectral images, although it revealed fairly accurate results, it was not used for short- and long-term analysis due to the limited availability of PRISMA images, compared to the more extensive Sentinel and Landsat collections.

Results

The long-term analysis indicates distinct erosion patterns in the southern region of Arborea Beach, as illustrated in Figure **2**. Over the analysed 20-year period, the northern region showed stability, characterised by alternating phases of accretion and erosion, as evidenced by the data from transect 2 (B) and 5 (C). Notably, Figure 2 highlights that transect 14 (E) demonstrates a gradual erosion trend, which has become more pronounced over the last decade of the analysis.

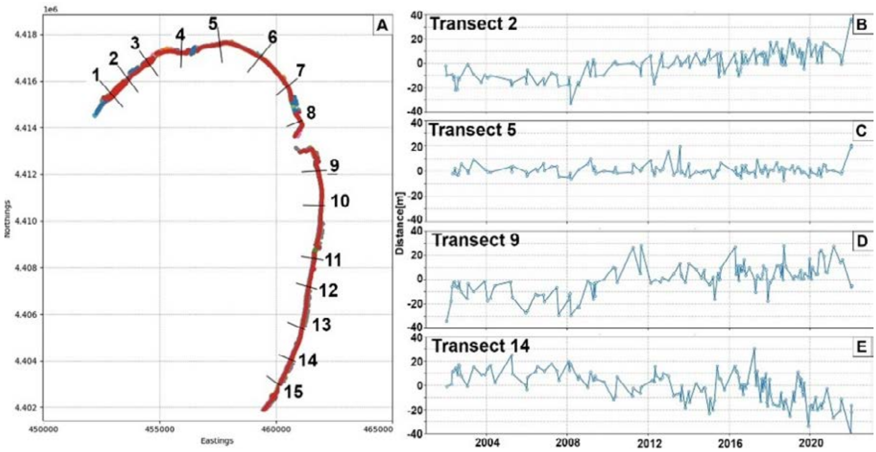

Figure 2 – A) CoastSat shorelines analysis (2002-2022); B), C), D), E) shoreline evolution along transects 2, 5, 9, 14, respectively.

This same trend was also observed in the short-term analysis conducted using the Shoreline Analysis and Extraction Tool (SAET), as depicted in Figure 3. Indeed, the Linear Regression Rate (LRR) values demonstrate predominantly positive values in the northern part of the Gulf of Oristano, indicating areas of accretion. However, there are localized areas within this region where the LRR values are negative which identifies beach erosion. The application of the DSAS tool revealed also significant erosion trends at Arborea Beach. Specifically, the DSAS analysis indicated a high rate of erosion, up to 15 meters per year (Table 1).

Table 1 – DSAS statistic on the beaches of the Gulf of Oristano.

Position	Trend	Name beach	Rate m/y
Area 1	Erosion	Arborea	>15
Area 2	Accretion	Abbarossa	>5
Area 3	Stable	Torre Grande	0
Area 4	Accretion	Mare Morto	>1

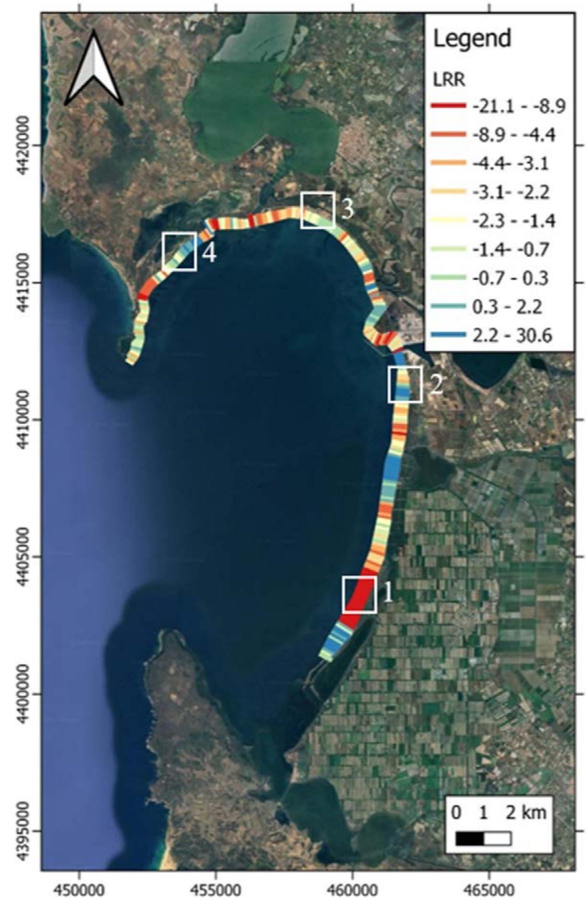

Figure 3 – Short-term shorelines analysis of the Gulf of Oristano from SAET algorithm (2022-2024). DSAS transects and Linear Regression Rate (LRR) statistical analysis (m/y). Area 1 correspond to Arborea beach; Area 2 correspond to Abbarossa beach; Area 3 correspond to Torre Grande beach and Area 4 correspond to Mare Morto beach.

The comparison with RTK-GNSS data is shown in Figure 4, where a notable correlation emerges between the SDS extracted using SAET and the location of the shoreline extracted with CoastSat. This correlation is particularly evident as the shoreline consistently appears shifted towards the sea in all three cases. On the other hand, the shoreline extracted using SAET algorithms seems to follow the path of the GPS shoreline. This is particularly evident in the second image, which correspond to an average distance between the shorelines of less than 1 meter (Table 2). In the first two figures a large amount of *Posidonia oceanica* is visible on the swash area as well as floating on the water while in the third one the Posidonia is absent.

The error analysis revealed that the SAET algorithm exhibited the lowest error, with an average error of approximately 5 meters (Figure 5). Conversely, the CoastSat algorithm demonstrated the highest error, as indicated by its Root Mean Square Error (RMSE) (Table 2).

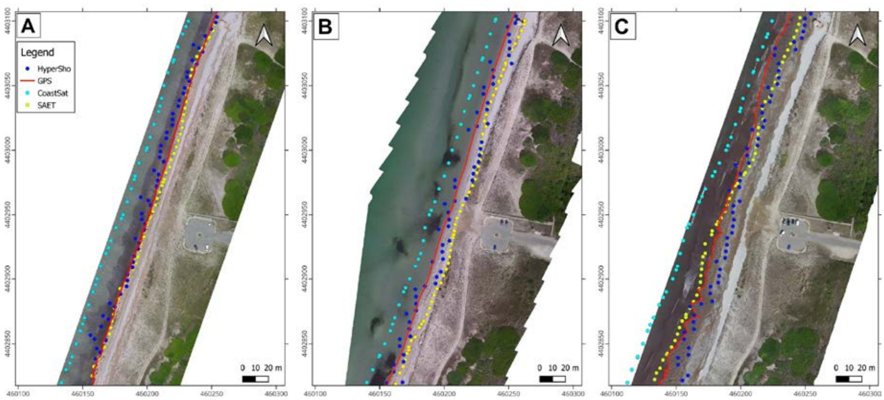

Figure 4 – Maps of shoreline extractions: A) SDSs and drone flight basemap of 18 September 2022; B) SDSs and drone flight basemap of 23 May 2023; C) SDSs and drone flight basemap of 10 October 2023.

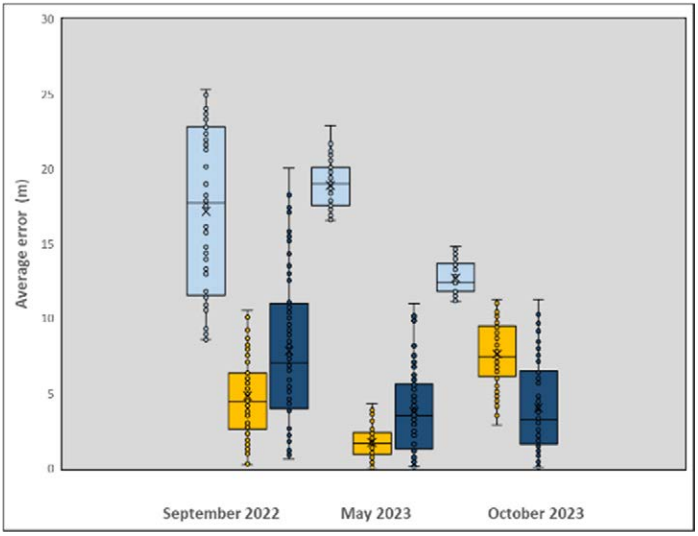

Figure 5 – Boxplot of the error analysis. In yellow SAET algorithm, in clear blue CoastSat algorithm and in dark blue HyperSho algorithm.

Furthermore, the error tends to be higher for CoastSat in cases with more Posidonia and lower with less Posidonia.

Regarding HyperSho, the error is comparable to that found by SAET, and the results do not appear to be affected by the presence or absence of Posidonia.

Table 2 – Error analysis of the SDSs.

Algorithm	RMSE of the algorithm	Date	Error	Value (m)
CoastSat	< 10 m	September 2022	Average	17.14
			St.dev	5.63
		May 2023	Average	18.88
			St.dev	1.54
		October 2023	Average	12.70
			St.dev	1.16
SAET	> 3 m	September 2022	Average	4.81
			St.dev	3.04
		May 2023	Average	1.72
			St.dev	1.06
		October 2023	Average	7.62
			St.dev	2.14
HyperSho	> 6 m	September 2022	Average	7.81
			St.dev	5.11
		May 2023	Average	3.76
			St.dev	2.67
		October 2023	Average	4.01
			St.dev	2.95

The one-year analysis revealed an erosional state throughout the beach, with only a few episodes of accretion of up to 10 meters (Figure 6). The accretion is mainly observed on the southern part (transect 10) adjacent to a pier.

In addition, a major storm event occurred in March 2023 with a peak of wave height of 3.96 m (Fig. 7), which allow us to analyse its effects on the beach (Fig. 6).

Figure 6 illustrates erosion and accretion events, especially along transects 10 to 20.

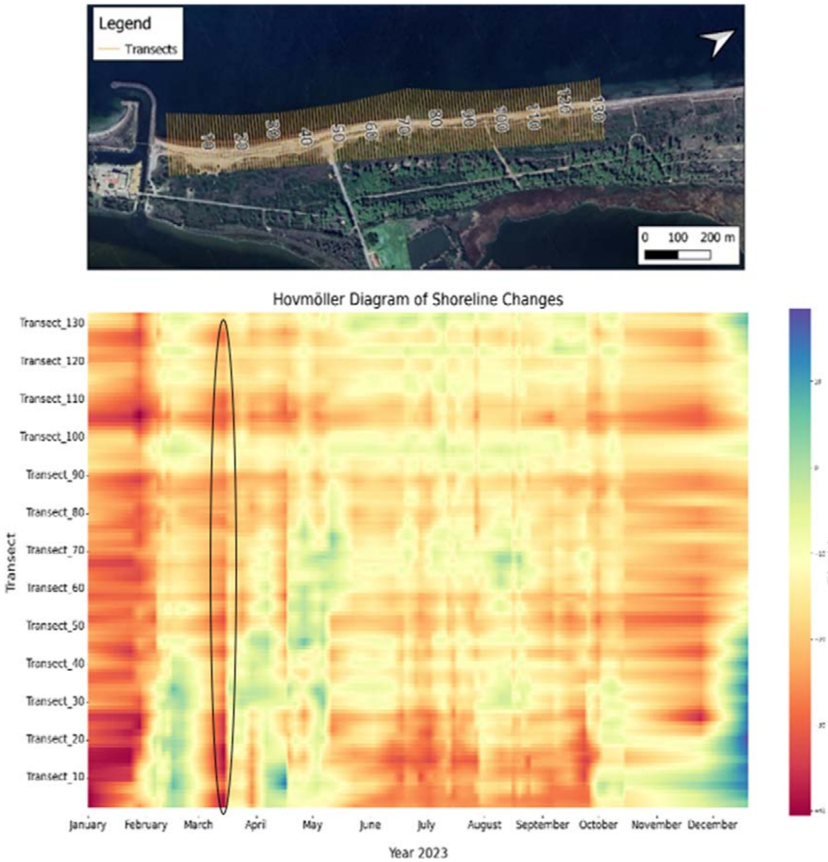

Figure 6 – Hovmöller diagram of shoreline changes on Arborea beach. The event occurred in March 2023 is highlighted.

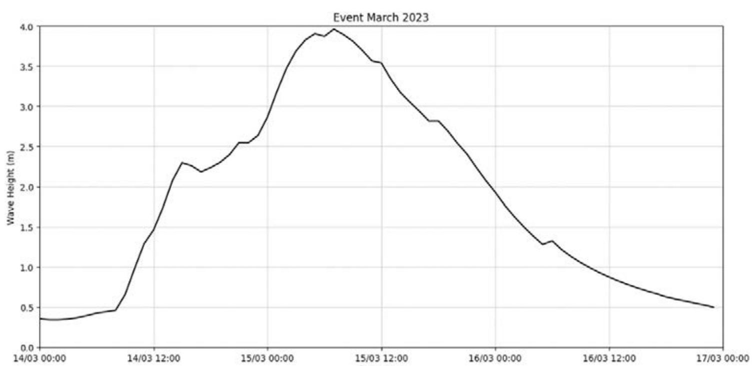

Figure 7 – Significant wave height during the event of March 2023. The data was obtained from the Copernicus Marine Environment Monitoring Services (CMEMS); the selected point was located in the entrance of the Gulf of Oristano (coordinate point: 8.4139.81).

Discussion

The results of the analyses showed how the evolution of the beaches of the Gulf of Oristano appear to reflect the dominant marine processes. In particular, the dynamics in the northern part of the gulf appear to be quite stable. In contrast, significant erosion is observed at Arborea beach in the southern part. Conversely, accretion occurs at Abbarossa beach, likely due to the presence of the harbour jetty acting as a sediment trap [16]. However, this accretion does not seem to match the rate of erosion occurring further south.

Consequently, there appears to be an overall loss of sediment in the region. Several hypotheses could explain this trend. The analysis conducted in 2023 highlighted the occurrence of significant storm surge events throughout the year. These events were confirmed through the examination of satellite images and were noted to occur even during the summer months, albeit with varying intensities. This erosional trend may be caused by the greater influence of extreme events on the most exposed area, specifically Arborea Beach. This discussion aligns with the research conducted by [16]. In the 2D simulation of water circulation in the Gulf of Oristano, the central area, including Arborea Beach, was shown to experience the highest retreat rates under both Mistral and southwestern wind conditions. Additionally, sediment trapping zones were identified in the southern portion of the gulf, near Capo Frasca, which could explain the loss of sediment in the system.

Another hypothesis suggests that erosion may be linked to the reduced sediment supply from the River Tirso and the presence of jetties, which could obstruct sediment circulation [17]. Consequently, this may increase the area's susceptibility to erosion driven by storm events. These aspects should therefore be investigated further through a historical analysis of the shoreline in the entire Gulf of Oristano.

The results also showed that detailed error analysis, comparing SDS with RTK GPS surveys, as in the study conducted for Arborea Beach, confirms the robustness of the method for temporal analysis with greater accuracy than traditional validation methods using orthophotos, which are subject to operator-dependent errors [18].

In addition, the results were found to be in agreement with the error calculated by the authors for the respective algorithms, remaining about 3 meters for SAET [8], sometimes even reaching lower values of 2 meters, and 6-7 meters for HyperSho [13]. In contrast, the CoastSat [7] algorithm produced a larger error, approximately 17 meters compared to less than 10 meters reported by the authors, likely attributable to specific beach conditions. This issue warrants further investigation in future studies, including an assessment of the influence of *Posidonia oceanica* debris on shoreline detection.

This detailed approach enabled the selection of the algorithm that operates most effectively within that specific context and under site-specific conditions, such as the presence of *Posidonia oceanica*.

The long-term temporal analysis enabled the identification of erosion and accretion trends that occurred over time, as well as the events that may have caused fluctuations in these trends [19]. These insights will serve as important elements for analysis in future studies, contributing to a deeper understanding of the coastal dynamics at the Gulf of Oristano.

The implementation of automatic shoreline extraction from optical satellite images supported the temporal analysis, including the evaluation of the errors inherent to the extraction process due to the limitations of the respective algorithms. For instance, while CoastSat provides the capability to perform an automatic temporal analysis, it shows limitations when extracting coastlines for extensive areas, leading to outliers and large errors.

Conversely, SAET is more effective for large areas; however, the process of shoreline extraction from a substantial number of images is less automated and more time-consuming.

Conclusions

The analysis showed erosive trends observed in both the short-term and long-term periods on sandy beaches located in the Gulf of Oristano. This has made it possible to investigate in detail the potential causes of erosion/accretion trends and has the potential to reconstruct historical records of extreme and non-extreme storm events. Such insights provide a clearer understanding of the extent to which these events have influenced the evolution of the coastal environment.

The results obtained from this work represent a useful methodological approach to monitor the shorelines with high frequency information and the related morphological changes, by using multispectral satellite imagery with relatively short revisit time and a large availability of images.

Finally, the semi-automatic procedures represent a way to facilitate the shoreline detection and to minimise the subjectivity due to human intervention.

Acknowledgements

This work is a contribution to the OVERSEE Project, financed by ASI under contract 2022-14-U.0. We also acknowledge the support of the staff of the CNR-IAS institute for providing access to local GPS corrections and logistical support. S. Terracciano acknowledges a PNRR-DM351 grant to the EMAS PhD program. A special acknowledgment is extended to Juan Pedro Carbonell-Rivera from the Universitat Politècnica de València (UPV) for providing the image used in Fig. 6.

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SESSION

COASTAL AND OFFSHORE ENGINEERING: ENERGY PRODUCTION AND TRANSPORT, PORT AND OFFSHORE STRUCTURES, WATER QUALITY, MEASUREMENTS AND MONITORING, DATA PROCESSING AND SERVICES, DIGITAL TWINS, ECONOMIC-ENVIRONMENTAL ASSESSMENT, REGULATORY CONTEXT

Chairperson: Lorenzo Cappietti
Department of Civil and Environmental Engineering
University of Florence

COASTAL AND OFFSHORE ENGINEERING:
Energy Production and Transport, Port and Offshore Structures, Water Quality, Measurements and Monitoring, Data Processing and Services, Digital Twins, Economic-Environmental Assessment, Regulatory Context

This session on coastal and offshore engineering aims at bringing together presentations of scientific works dealing with the following topics: energy production and transport, port and offshore structures, water quality, measurements and monitoring, data processing and services, digital twins, economic-environmental assessment and regulatory context. The session successfully met its objective, bringing together 21 researchers who presented their work. Of these, 19 submitted full papers, which are now published in these conference proceedings.

Most of the papers (8 out of 19) focus on water quality issues related to various pollutants, including chemical substances, plastic particles, and oil spills (Compa and Sureda 2024, Ballerini et al. 2024, Liubartseva et al. 2024, Özkaynak and İçemer 2024, Galeano et al. 2024, Morales-Aragón et al. 2024, Mance et al. 2024a, Locuratolo et al. 2024). The implications of climate change, particularly sea level rise and its consequences for coastal protection and salinization, are addressed in four papers (Sabattini et al. 2024, Simoncini 2024, Zannella et al. 2024, Mance et al. 2024b). Two articles (de Virgilio et al. 2024 and Azzopardi 2024) explore the use of machine learning techniques to predict meteomarine conditions and algal blooms. The remaining articles present research on numerical wave flumes and tanks by using computational fluid dynamics (Liu et al. 2024 and Abdollahpour et al. 2024), data management (Pecci et al. 2024), digital twinning (Tsaimou and Tsoukala 2024), and marine renewable energies (Marini and Sulis 2024).

Compa and Sureda (2024) and Ballerini et al. (2024) both highlight the serious issue of plastic pollution in marine environments. Compa and Sureda emphasize the ecological and economic consequences of plastic pollution, including harm to marine life, damage to infrastructure, and negative impacts on tourism. They stress the need for stricter global regulations to address this issue. Ballerini et al. provide a quantitative assessment of plastic pollution on Tuscan beaches, revealing high levels of contamination. They analyze the environmental measures implemented by local municipalities, identifying both strengths (e.g., potential for local action) and weaknesses (e.g., resource constraints, regulatory limitations). Both studies underscore the importance of collaborative efforts between municipalities, research institutions, and citizens to develop effective strategies for reducing plastic pollution and transitioning towards more sustainable practices.

Liubartseva et al. (2024) presented a work on oils spill focused on the HAVEN oil spill of 1991, a significant event with long-lasting ecological and economic consequences. The researchers used the MEDSLIK-II model to simulate the oil spill's trajectory and once validated the model was used to assess future risks by

FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Laura Bonora, Marcantonio Catelani, Matteo De Vincenzi, Giorgio Matteucci (edited by), *Tenth International Symposium "Monitoring of Mediterranean Coastal Areas: Problems and Measurement Techniques". Livorno (Italy) 11th-13th June 2024*, © 2024 Author(s), CC BY-NC-SA 4.0, published by Firenze University Press, ISBN 979-12-215-0556-6, DOI 10.36253/979-12-215-0556-6

means of stochastic simulations of the HAVEN spill scenario in different Med. Sea sites. This analysis identified areas of high oil pollution hazard, particularly the Algerian subbasin, eastern Alboran Sea, Liguro-Provençal subbasin, and central Ionian Sea. The results of this study are valuable for organizations involved in oil spill response and preparedness planning, as they provide insights into potential future scenarios and areas of high risk.

Özkaynak and İçemer (2024) studied the amount of ballast water discharged by ships in Antalya Bay. They found that using deadweight tonnage to estimate ballast water can be inaccurate, potentially affecting assessments of environmental impact. They emphasize the need for future research to analyze the presence of harmful organisms and pathogens in ballast water to better understand its ecological consequences. The study also highlights the importance of proper ballast water management in ports, emphasizing the need for regulations to ensure that waste reception facilities handle ballast water to mitigate environmental risks.

The works by Galeano et al. 2024, Morales-Aragón et al. 2024, Mance et al. 2024a, and Locuratolo et al. 2024 are all related to water quality, focusing on different aspects. The work of Galeano et al. 2024 presents the results of the Italian Coast Guard surveillance. Over 2000 checks carried out led to the detection of numerous crimes, both administrative and penal, regarding waste and in particular water discharges. Morales-Aragón et al. (2024) developed a new lightweight, autonomous profiler designed for monitoring shallow marine environments. This innovative tool can contribute to better understanding and management of shallow marine ecosystems, particularly in relation to hydrodynamic modeling and the prevention of adverse events like anoxia. Mance et al. (2024a) compared different methods for assessing the quality of marine bathing waters. They found that while parametric methods are more rigorous, they often require normally distributed data, which is not always the case for bacteriological water pollution. Non-parametric methods, like the Hazen method, may be more suitable for these situations. However, the authors caution that the results may not be fully representative due to the limited number of sites studied. Locuratolo et al. (2024) used a numerical model to simulate the dispersion of pollutants from a combined sewer overflow in Bari, Italy, during and after heavy rainfall. The model successfully reproduced the observed patterns of turbidity and bacterial contamination in the surrounding waters. While the model provided valuable insights, the researchers noted limitations in the available data, particularly regarding oceanographic conditions. Despite these limitations, the model can be a useful tool for early warning systems to predict and mitigate the impact of pollution events on bathing water quality.

The works by Sabattini et al. (2024) and Mance et al. (2024b) both focus on the issue of salinization in coastal areas and climate change effects. Sabattini et al. studied seawater intrusion in the Magra River estuary and alluvial plain (Italy), particularly during a recent period of severe drought. They found that Magra river discharge and wind speed significantly influence saltwater intrusion. The natural weir at Romito currently limits seawater intrusion, but future sea level rise could compromise this natural barrier. Mance et al. investigated salinization in springs in Bakar Bay (Croatia). They concluded that seawater intrusion, combined with increased temperatures and evaporation rates, is responsible for the rising chloride concentrations in these springs. This highlights the vulnerability of karst regions to climate change impacts.

Simoncini (2024) and Zannella et al. (2024) both focused on the impact of climate change on coastal areas. Simoncini (2024) used Miami as a case study to highlight potential adaptation strategies for Mediterranean coasts, including elevating infrastructure, implementing water management systems, and constructing storm surge barriers. Zannella et al. (2024 presented a specific case study in Marina di Pisa, Italy, where a novel storm defence system involving artificial gravel nourishments and submerged breakwaters was implemented to mitigate coastal flooding.

The works by de Virgilio et al. (2024) and Azzopardi (2024) explored the application of artificial intelligence (AI) in marine science. De Virgilio et al. used AI to predict the occurrence of harmful algal blooms (O. ovata) based on weather parameters. They found that a small set of weather data can accurately predict these blooms. Azzopardi (2024) employed AI to extend marine weather forecasts. Their research emphasized the importance of large datasets for training AI models, suggesting that models trained on global data or data from nearby stations often outperform those trained on limited local data.

Liu et al. (2024) and Abdollahpour et al. (2024) presented work on the development of numerical wave flumes and basins using computational fluid dynamics (CFD) methodology. This demonstrates the power of CFD as a tool for studying complex wave-structure interactions and the potential benefits of leveraging high-performance computing.

Pecci et al. (2024) presented the EMODnet Data Ingestion initiative, which aims to promote data sharing and reuse in marine science. By making data openly accessible, this initiative facilitates knowledge dissemination and fosters a culture of data sharing among researchers.

Tsaimou and Tsoukala (2024) proposed guidelines for developing digital twins (DT) of port infrastructure, specifically focusing on concrete pavements and rubble mound structures. The DT would integrate data from various sources, including remote sensing inspections, condition assessments, and GIS-based geospatial data. This information can be used to monitor structural changes, detect damage, and inform maintenance decisions. By leveraging DT technology, port authorities can implement smart maintenance practices and improve the overall management of their infrastructure.

Marini and Sulis (2024) explored the potential of wind and wave energy in Sardinian coastal areas. They argue that these renewable energy sources, especially when combined in small-scale devices, can have a minimal visual impact. Additionally, they emphasize the importance of energy communities in promoting public acceptance and attracting investment in clean energy projects.

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NUMERICAL WAVE TANKS FOR WAVE ENERGY CONVERTERS USING HIGH-PERFORMANCE COMPUTING

Milad Abdollahpour, Federico Domenichini, Lorenzo Cappietti

Abstract: Numerical Wave Tanks (NWTs) powered by Computational Fluid Dynamics (CFD) and High-Performance Computing (HPC) offer a cost-effective and flexible alternative to physical wave tanks. They are essential for simulating complex wave phenomena and wave-structure interaction. This research explores the assessment of NWT reliability, particularly in HPC environments, using OpenFOAM, an open-source CFD toolbox. OpenFOAM's parallel processing capabilities leverage HPC to achieve accurate and efficient simulations of wave dynamics, crucial for optimizing wave energy converter designs and advancing renewable energy generation. HPC reduces execution time, enabling more comprehensive simulations and faster design optimization, ultimately accelerating progress in wave energy technologies. The study demonstrates OpenFOAM's suitability for NWT simulations while acknowledging the need for validation and optimization of grid and discretization methods.

Keywords: Numerical Wave Tanks (NWTs), CFD, OpenFOAM, Parallelization, High-Performance Computing (HPC)

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Milad Abdollahpour, Federico Domenichini, Lorenzo Cappietti, *Numerical Wave Tanks for Wave Energy Converters Using High-Performance Computing*, pp. 835-845, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.72

1. Introduction

Marine structures play a crucial role in our understanding of how they respond to environmental conditions, particularly ocean waves. These waves impose loads and movements that require precise analysis. Coastal areas are significantly impacted by water waves, affecting shoreline stability and offshore installations. Researchers employ specialized facilities like wave tanks and flumes to study these effects (Sierra and Casas-Prat, 2014). While physical modeling and field data collection remain valuable (Hughes, 1993), Numerical Wave Tanks (NWTs) have revolutionized coastal engineering research by providing a virtual platform for simulating complex wave-structure interactions (Simonetti et al., 2015). Researchers have explored NWTs and their applications since the 19th century, making them a powerful tool for studying various coastal engineering scenarios (Boo et al., 1994; Boo and Kim, 1997, 1997; Cointe and Geyer, 1991; Dommermuth and Yue, 1987; Grilli and Horrillo, 1998; Longuet-Higgins and Cokelet, 1976; Nojiri, 1980; Tanizawa and Naito, 1997; Vinje and Brevig, 1980). In recent years, several systematic studies have been found with NWTs and their application in different analyses. They excel in simulating wave interaction with various structures, including floating platforms used in offshore operations and wave energy converters (e.g. Didier and Teixeira, 2024; Olbert and Abdel-Maksoud, 2023; Qian et al., 2005; Simonetti and Cappietti, 2017; Zullah et al., 2010); coastal erosion and evaluating the effectiveness of protection strategies (e.g. (Dao et al., 2018; Jin et al., 2022; Qian et al., 2023); ship motion and stability in wave conditions (e.g. Contento, 2000; Sen, 2016; Zhuang and Wan, 2019).

Due to their increased complexity, these models require greater computational resources and longer computation times. Recent advancements in computational techniques have led to the development of Computational Fluid Dynamics (CFD) models. CFD models have allowed accurate simulation of wave behavior by providing detailed flow information across different scales, device shapes, and wave conditions (Liu et al., 2014; Robaux and Benoit, 2021; Silva et al., 2015; Simonetti et al., 2018, 2014; Simonetti and Cappietti, 2017; Windt et al., 2019). The availability and development of High-Performance Computing (HPC) have resulted in a consistent increase in CFD-based NWTs (CNWTs) in recent years. The integration of Computational Fluid Dynamics (CFD) and High-Performance Computing (HPC) within NWTs plays an important role in simulating and optimizing complex interactions between waves and applications, offering cost-effective experimentation and a deeper understanding of fluid dynamics. High-fidelity simulations require precise consideration of parameters, and HPC's parallelization capabilities efficiently handle vast datasets, enabling simulations with finer spatial and temporal resolutions and critical for resolving small-scale features.

HPC has become a critical tool in advancing various fields including hydraulics (Sotiropoulos, 2015), offshore renewable energy (Ouro et al., 2021; Stoesser, 2014); tidal flow (Stansby and Ouro, 2022) water resources hydrodynamics (Morales-Hernández et al., 2020) have leveraged HPC to model complex fluid dynamics, demonstrating the transformative impact of computational power which is crucial for engineering applications. Despite HPC's transformative impact across related fields, there remains a significant gap in research specifically targeting offshore applications, highlighting the need for more focused efforts in Numerical Wave Tanks (NWTs) to fully exploit HPC's capabilities and achieve significant breakthroughs in these areas. This research investigates a methodology for assessing the reliability and accuracy of CFD-based NWTs, specifically within the context of HPC simulations. OpenFOAM, a versatile open-source CFD toolbox, is employed for these simulations. Grid convergence tests are conducted to ensure numerical solutions achieve the desired level of accuracy. By delving into this area, the aim is to establish a robust framework for utilizing HPC-powered NWTs with confidence, focusing on the way for more efficient and optimized designs offshore structures.

2. Materials and Methods

2.1. Set-Up of the Numerical Simulations

Numerical simulations were performed using OpenFOAM V-2306, considering the two-dimensional geometry of the physical wave flume available at the Laboratory of Maritime Engineering (LABIMA) at the University of Florence. The flume has dimensions of 37 meters in length, 0.8 meters in width, and 0.8 meters in height. Figure 1 illustrates the geometry of the wave tank.

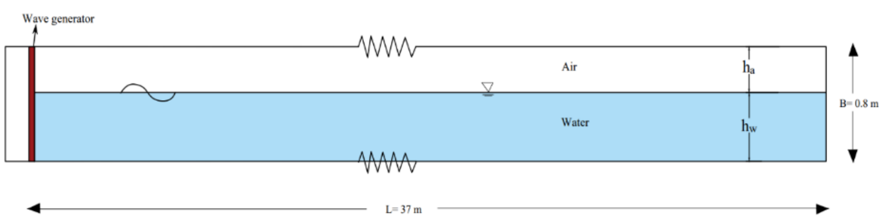

Figure 1 – Sketch of wave flume (not to scale). Overview of the simulation setup following the physical experiments, where h_w and h_a, represent the water depth and height of the air region, respectively. L and B are the length and height of the flume, respectively.

In multiphase flows, topologically orthogonal meshes with their axis aligned with the fluid interface tend to show fewer numerical problems. In OpenFOAM, geometries for internal flows are typically created using a meshing tool, known as blockMesh, which creates fully structured hexahedral meshes. A fine mesh near the free surface is needed to capture the details of wave crests, troughs, and their interactions. As shown in Figure 2, the mesh was gradually refined free surface.

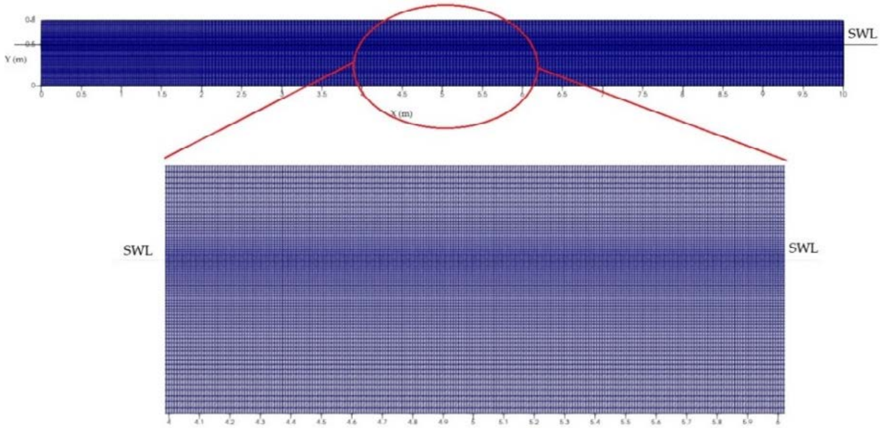

Figure 2 – The general view of the grid and zoom of the grid in the vicinity of the water surface.

The Volume of Fluid method (VOF) is used to resolve the two-phase (air and water) flow. Both phases are assumed to be incompressible, at a constant temperature, and incapable of mixing. Table 1 shows a summary of the physical properties of models.

Table 1 – Summary of physical properties of models.

Parameter		**Value**
Gravity (m/s2)		g = 9.81
Density (kg/m³)	Water	$\rho_w = 1000$
	Air	$\rho_a = 1$
kinematic viscosity (pa/s)	Water	$\upsilon = 10^{-5}$
	Air	$\upsilon = 1.48 \times 10^{-4}$

The boundary conditions are crucial elements determined by the specific requirements of each numerical solution. In this study, the Inlet and Outlet boundaries are especially significant for implementing the CFD-based NWT. The inlet boundary generates the wave, while the outlet boundary ensures the fluid exits without backflow. A summary of these boundary conditions which were used is given in Table 2.

Table 2 – Summary of boundary condition implemented in OpenFOAM.

Boundary	Pressure (p_rgh)	Velocity (u)	alpha.water
Inlet (left wall – piston type wave maker)	fixedFluxPressure	movingWallVelocity	zeroGradient
Bottom	fixedFluxPressure	fixedValue	zeroGradient
Outlet (right wall)	fixedFluxPressure	waveVelocity	zeroGradient
Top (Atmosphere)	totalPressure	pressureInletOutletVelocity	inletOutlet

2.2. Computational resource

In this research, we used a diverse range of computational resources optimized for specific computational tasks. These resources include a workstation and the CINCA HPC system in Italy, one of the world's leading supercomputer clusters.

The workstation, equipped with a Core i9-9900K CPU running at 3.6 GHz, features 8 cores and 16 GB of RAM. It is utilized for moderately demanding simulations and preliminary data analysis. For more intensive computational tasks, we leverage the CINCA HPC system. This system comprises Intel Xeon Platinum 8260 processors running at 2.4 GHz, with each processor featuring 24 cores. The HPC system consists of 48 nodes, each with 384 GB of RAM, a total of 554 nodes. This architecture exploits parallel processing, allowing numerous processors to work concurrently on different segments of a task. As illustrated in Figure 3, workload distribution across these processors enhances efficiency and speed, employing advanced techniques such as distributed computing and optimized algorithms to deliver rapid and precise results for complex simulations.

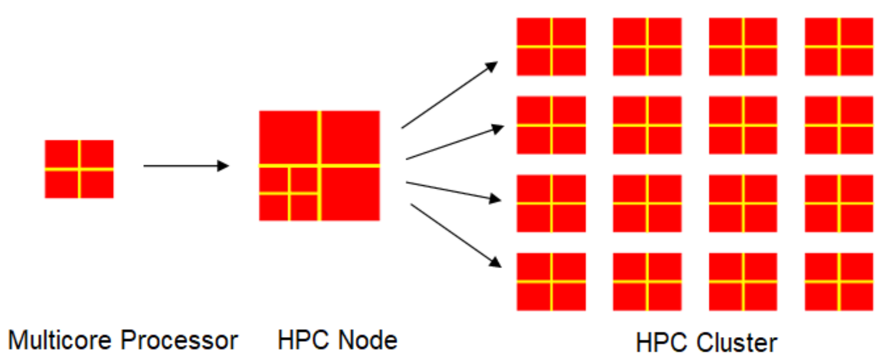

Figure 3 – Overview of High-Performance Computing (HPC) Architecture.

3. Results and discussion

3.1. Grid convergence tests

It is crucial to perform a dedicated validation focused on wave accuracy in the numerical simulation before comparing experimental data. This validation, as suggested by Coe and Neary (Coe and Neary, 2014), helps to minimize potential errors and ensures a reliable foundation for the main investigation. Mitigation strategies exist for each category to improve simulation accuracy (Oliveira et al., 2022). A precise Numerical Wave Tank (NWT) involves initial tests to determine how the size of the grid and the time steps influence the simulated waves. To find the optimal spatial and temporal discretization size—specifically the time step and cell size—researchers conduct convergence studies based on regular wave data (Windt et al., 2020). Regular waves, defined by their consistent wave height, period, and wavelength, are fundamental benchmarks in coastal engineering for analyzing wave behavior. In this study, the regular waves are characterized by a period of 1 second, a wavelength of 1.56 meters, a height of 0.1 meters, and a water depth of 0.5 meters. Spatial discretization is categorized by the number of cells per wave height (CPH), the number of cells per wavelength (CPL), and the maximum cell horizontal-to-vertical aspect ratio (AR). The temporal discretization is categorized using fixed or variable time steps, where the latter is controlled through the Courant Friedrichs Lewy (CFL) condition. A convergence analysis was conducted to determine the optimal balance between spatial and temporal discretization for accurate wave simulations within the long Numerical Wave Tank. This analysis focused on six cases, exploring the impact of CPH and CPL on accuracy. Table 3 summarizes the discretization schemes investigated for the cases, including variations in CPL and CFL.

Table 3 – Summary of discretization schemes investigated for grid convergence study.

Test Case	Number of cells	CPL	CPH	ΔT	AR
Case 1	62 900	80 - 215	11-30	T/1000	<2.2
Case 2	99 330				
Case 3	150 000				
Case 4	296 000				
Case 5	421 800				
Case 6	579 700				

CPH: number of cells per wave height; CPL: number of cells per wavelength; AR: aspect ratio; T: wave period.

Convergence analysis of various discretization schemes (CPH and CPL) identified a minimum cell requirement for accurate and efficient wave simulations in an NWT. By analyzing the convergence trends across different CPH and CPL combinations, we aimed to identify the minimum number of cells required to achieve a desired level of accuracy while maintaining computational efficiency.

The results indicate convergence in free surface elevation for cases with Cells per Wavelength (CPL) greater than 160 and Cells per Wave Height (CPH) greater than 21. This convergence balances accuracy and computational efficiency in the High-Performance Computing (HPC) cluster. Three cases (Cases 4, 5, and 6) were selected for parallel processing on a multiprocessor system to explore this efficiency further. The analysis will assess the scalability and effectiveness of utilizing HPC for NWT simulations.

3.2. Development of Model Parallelization on HPC

The high computational cost associated with long-wave tank simulations necessitates parallel computing for efficient analysis. OpenFOAM, a popular CFD software, facilitates model parallelization on HPC systems. In this study, we explored the capabilities of an HPC system with 24 cores. We investigated the impact of using 1, 4, 8, 16, and 24 processors on the simulation runtime within the long wave tank for three cases, resulting in a total of 15 tests. Table 4 presents the computational resources available for this study. It details the configurations used, including the workstation and the High-Performance Computing (HPC) system with various processor allocations.

Table 4 – Computational Resources and Processor Allocations.

Computational resources	Number of Processor used
Workstation (Desktop) (Core i9-9900K, CPU@ 3.6 GHz, With 8 cores and 16 GB RAM)	1
HPC (Intel Xeon Platinum 8260 @2.4 GHz 24 cores each, total Nodes 48*554 / 554 with 384 GB RAM)	1
	4
	8
	16
	24

Figure 4 shows the impact of utilizing varying processor cores on the computational time within the HPC environment for 2D NWT simulations. The results reveal promising trends in terms of parallel speedup but also highlight potential limitations as the number of cores increases.

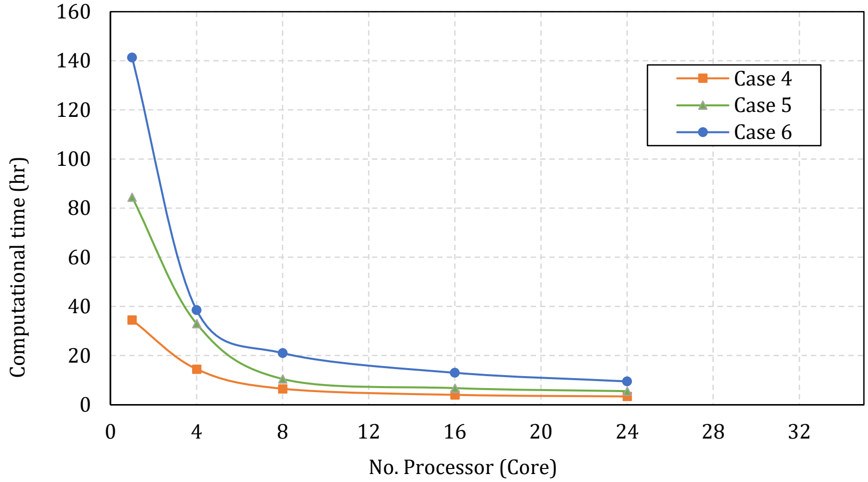

Figure 4 – Parallel Scaling Performance for 2D Numerical Wave Tank within HPC.

The observed speedup closely follows the linear scaling up to 4 processors, demonstrating efficient utilization of HPC resources. Further scaling to 16 cores maintains a nearly linear relationship, indicating continued strong performance. However, a slight degradation in speedup is observed when increasing from 16 to 24 cores. This deviation from ideal scaling suggests potential limitations due to factors such as increased communication overhead within the HPC system. These findings align with typical parallel computing trends, where initial strong scaling is often followed by diminishing returns as the number of cores increases. Addressing these limitations could involve optimizing communication patterns or exploring alternative parallelization strategies to maximize HPC efficiency.

Conclusion

This study investigated the suitability of Numerical Wave Tanks (NWTs) for simulating wave-structure interactions, focusing on the importance of grid convergence and the potential benefits of High-Performance Computing (HPC). A grid convergence analysis identified optimal cell sizes for accurate wave representation, ensuring reliable simulation results. HPC capabilities demonstrated strong parallel scaling, indicating efficient resource utilization. However, declining returns were observed as the number of cores increased, indicating potential limitations due to communication overhead. Overall, the study highlights the critical role of HPC in advancing coastal engineering simulations.

These findings underscore the importance of careful grid selection and the potential of HPC to accelerate 3D NWT simulations. Further research could explore advanced parallelization techniques and hardware optimizations to maximize HPC efficiency.

Acknowledgments

The University of Florence acknowledges the contribution of the National Recovery and Resilience Plan, Mission 4 Component 2 - Investment 1.4 - NATIONAL CENTER FOR HPC, BIG DATA AND QUANTUM COMPUTING, funded by the EU - NextGenerationEU - (CUP B83C22002830001).

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AI AND MACHINE LEARNING TO EXTEND METEO-MARINE STATION OBSERVATIONS INTO THE FUTURE

Joel Azzopardi

Abstract: The real-time availability of data from coastal meteo-marine stations is crucial for various stakeholders, including port authorities, government agencies, researchers, and the general public. While observation data is fundamental, short-term forecasts can significantly enhance planning and decision-making processes. This study explores the application of Machine Learning (ML) techniques to predict hourly values of air temperature, wind speed, atmospheric pressure, and humidity for the next 24 hours. We evaluate three ML models: Long Short-Term Memory Network (LSTM), Random Forest (RF), and Multivariate Linear Regression (LR). The models were trained using Python libraries and Optuna for hyperparameter tuning on datasets of varying lengths from stations in the Malta-Sicily channel. Additionally, we investigated transfer learning with the ERA5 dataset, which provides hourly values over an 83-year period, to address the challenge of limited data availability. The results show that models trained on longer datasets generally achieve better performance. Furthermore, the models demonstrated considerable generalizability, particularly across nearby stations, allowing models trained at one station to be effectively used for predictions at other proximate stations. To support further research and practical application, we have made our models and tools publicly available.

Keywords: Machine Learning, Artificial Intelligence, Transfer Learning, Meteorology, Prediction

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Joel Azzopardi, *AI and Machine Learning to extend Meteo-Marine Station Observations into the Future*, pp. 846-857, DOI: 10.36253/979-12-215-0556-6.73

Introduction

The real-time availability of data from coastal meteo-marine stations is becoming increasingly important. This data is indispensable for stakeholders such as port authorities, government agencies, researchers, and the public. While real-time (now-cast) data is essential, short-term forecasts for the upcoming hours would provide significant additional benefits. The integration of Artificial Intelligence (AI) and Machine Learning (ML) techniques is pivotal in generating these forecasts. Recent advancements in technology and reductions in costs have led to a proliferation of coastal station installations. Notably, a number of stations have been established in the Malta-Sicily channel as part of the i-waveNet project [3]. Real-time observations from these stations are accessible through the i-waveNET Decision Support System developed by the University of Malta [4].

While nowcasts (near-real-time observations) are vital, their utility would be greatly enhanced by incorporating short-term forecasts based on these observations. This paper explores our research into using ML to project coastal stations' observational data into the future. A significant challenge we face is the limited amount of data available for training, as most stations have only become operational in recent months. The literature suggests that deep learning models, especially Long Short-Term Memory Networks (LSTMs), are highly effective but require extensive datasets; even a three-year dataset of hourly observations is often insufficient to train an LSTM effectively.

We evaluate the performance of three ML architectures—Long Short-Term Memory Network (LSTM), Random Forest (RF), and Multivariate Linear Regression (LR)—to predict hourly values for air temperature, wind speed, atmospheric pressure, and humidity for the next 24 hours. To address the issue of limited available data, we conducted experiments with different training sets. We used a 32-month dataset from the Cirkewwa station (October 2020 - May 2023) and assessed how models trained on this dataset predict values for the Cirkewwa station and three other stations (two in Malta and one in southern Sicily) for November 2023. Additionally, we employed a one-month dataset from the Cirkewwa station (October 2023) to evaluate how models trained on it generate predictions for this station and the other three stations. Lastly, we trained a model for each station using data from October 2023 for that station and used these models to predict data for November 2023 for the same station.

The rationale behind experimenting with these different training datasets was to determine the extent to which long datasets are necessary for ML predictions across different parameters and to explore whether models can be generalised to apply across various stations. The outcomes help identify potential solutions for scenarios with sparse or missing data.

Furthermore, we explore the potential of using a long-term time series dataset from ERA5, provided by the Copernicus Climate Change Service (C3S), which offers meteorological hourly values from 1940 to 2022 at a coarse spatial resolution (0.5°) [6]. We performed experiments where we trained our models on this dataset and then fine-tuned them using station observational data.

Finally, we are making our model training code, prediction tools, and the best-performing pre-trained models for each parameter publicly available: https://ocean.mt/research/stationDataPredictions.zip

Related Research

Artificial Intelligence (AI) has demonstrated exceptional utility in short-term meteorological forecasting due to its ability to manage the complexities and vast datasets inherent in weather systems. Traditional numerical weather prediction models often struggle with the nonlinearities and high-dimensionality of weather data. In contrast, AI models, such as neural networks, excel in identifying complex patterns within large datasets without needing explicit physical modelling, leading to more accurate and timely forecasts.

AI has been widely applied to predict air temperatures, particularly local temperatures over short-term periods (typically 1 to 3 days in advance) [1, 8, 11]. Some studies have also focused on forecasting seasonal temperature variations [9]. Wind speed prediction, especially at a height of 10 metres, is another frequent application of AI [2, 10, 11, 13, 14]. Accurate wind speed forecasts are crucial due to the growing use of wind power generation and the necessity to predict energy output from wind sources. Other variables forecasted by AI models include humidity [11, 12, 18], atmospheric pressure [12], and rainfall/precipitation [16].

The AI architectures used to predict these meteorological parameters range from deep learning methods (like neural networks and Long Short-Term Memory networks, or LSTMs) to simpler machine learning techniques. LSTMs are particularly prevalent and have been successfully applied to predict wind speed [10] and air temperature [8, 11, 18]. Reports suggest that LSTMs often outperform other models. They are also frequently integrated into hybrid models, combined with other deep learning architectures such as Convolutional Neural Networks (CNNs) [11] and Convolutional Recurrent Neural Networks (CRNNs) [18], which have been reported to yield superior results.

While neural networks and deep learning techniques generally offer enhanced performance, they can struggle with limited training data. Some studies indicate that polynomial regression models outperform artificial neural networks when using a three-year dataset [2].

A popular alternative to deep learning models is Random Forests (RF). RF models are advantageous because they do not require the extensive training data that deep learning approaches do and have proven to be very effective in predicting meteorological variables. The reviewed literature shows that RF models are primarily used for predicting wind speeds [2, 13] and rainfall [15].

Support Vector Machines (SVMs) are another machine learning approach frequently employed in meteorological predictions. SVMs have been successfully used to forecast air temperature [1] and other general weather parameters [15]. Additionally, statistical methods like polynomial regressions have been applied to predict wind speed [2, 14].

Materials and Methods

The data used in this research comes from observations recorded at four coastal meteorological stations—three located in Malta and one in southern Sicily. These stations are depicted in Figure 1. In Malta, the stations are situated at Mgarr Gozo (blue), Cirkewwa (red), and Delimara (green), which are relatively close to each other. Mgarr Gozo is approximately 5 km from Cirkewwa, and Delimara is about 30 km from Cirkewwa. In contrast, the Sicilian station, Marina di Ragusa (yellow), is significantly farther away, approximately 90 km from Mgarr Gozo.

Each of these stations records the following observations at 1-minute intervals:

- Air Temperature
- Atmospheric Pressure
- Relative Humidity
- Wind Speed and Direction

For the period from October 1, 2023, to November 30, 2023, data from all four stations were aggregated into hourly intervals by simple averaging. Additionally, a longer dataset from the Cirkewwa station was available, containing hourly observations from October 5, 2020, to May 11, 2023. This dataset did not require further pre-processing.

Besides these datasets, we also utilised data from the ERA5 Reanalysis dataset for the period from January 1, 1940, to December 31, 2022. This dataset includes hourly observations for the geographical point at 14.50° longitude and 36.00° latitude, which is the closest to the Maltese Islands and most of the described stations. The ERA5 dataset, freely available from the Copernicus Climate Change Service, provides multiple meteorological variables from 1940 onwards at an hourly temporal resolution and a spatial resolution of 0.5°. For our research, we downloaded the following ERA5 parameters:

- 10 m u and v components of wind
- 2 m temperature
- 2 m dew point temperature
- Surface pressure

Pre-processing of the ERA5 data involved several steps: converting temperature from Kelvin to Celsius, calculating wind speed from the wind components, converting pressure from Pascals to millibars (mbar), and calculating relative humidity from the air temperature and dew point temperature. The relative humidity was computed using the formula provided below:

$$RH = 100 \times \frac{\exp\left(\frac{17.625 \times T_d}{243.04 + T_d}\right)}{\exp\left(\frac{17.625 \times T}{243.04 + T}\right)}$$

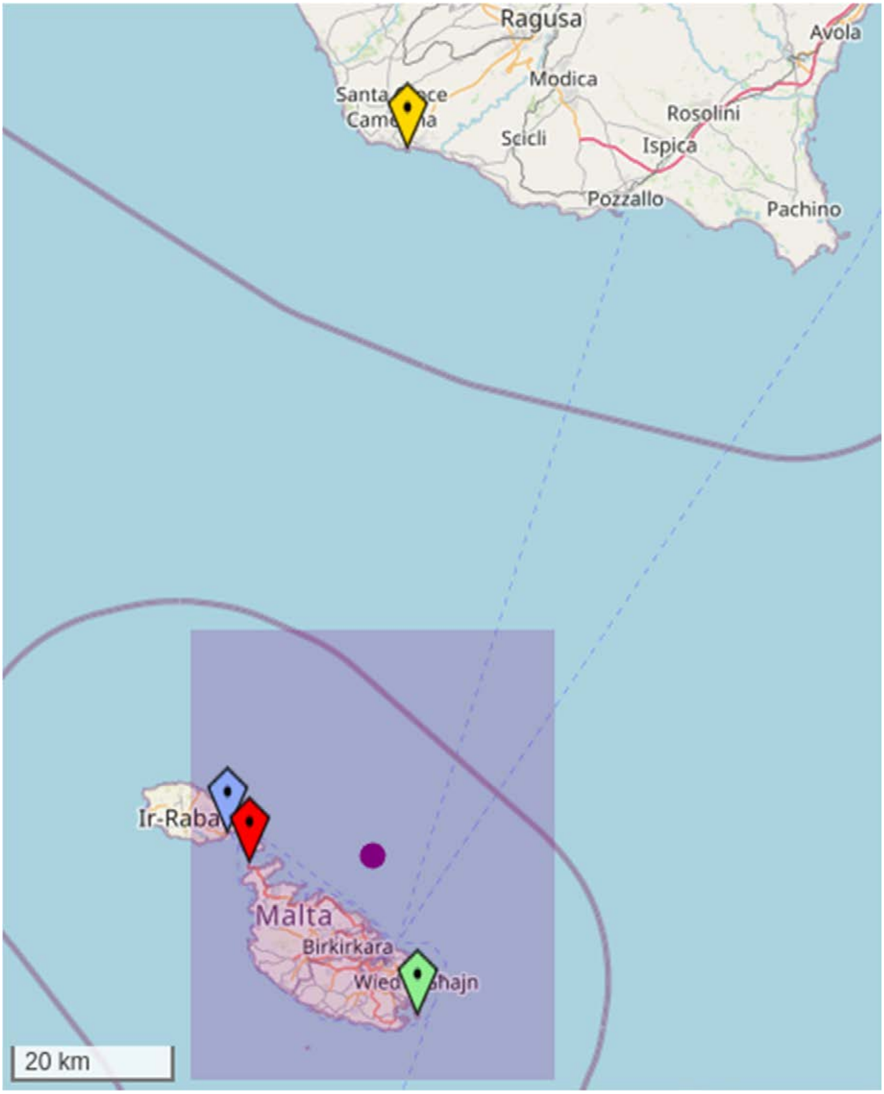

Figure 1 – Map displaying the locations of four stations in the WGS84 coordinate system: Marina di Ragusa (yellow marker, 14.5465°E, 36.7799°N), Mgarr Gozo (blue marker, 14.298°E, 36.024°N), Cirkewwa (red marker, 14.3296°E, 35.9906°N), and Delimara (green marker, 14.5589°E, 35.8217°N). The selected ERA5 reanalysis model cell is marked by a purple square with a central purple dot at 14.5°E, 36.0°N.

We employed three Machine Learning (ML) techniques in our study: Long Short-Term Memory Network (LSTM), Random Forest (RF), and Multivariate

Linear Regression (LR). LSTM and RF were chosen due to their proven success in the literature. LR was selected for its simplicity and its low data requirement for training. Our methodology involved using a lookback period of the past 48 hours of observations to predict the next 24 hours. For simplicity, our predictions always start at 0000 GMT each day. Specifically, each prediction (for the period from *0000* to *2300* of *Day 0*) was based on data from the lookback period *0000* of *Day -2* to *2300* of *Day -1*.

Separate models were trained for each target variable: air temperature, wind speed, atmospheric pressure, and relative humidity. The features used for the predictions included the observed values of air temperature, wind speed, atmospheric pressure, and relative humidity during the lookback period, as well as the hour of the day (0 – 23) and the current day of the year (1 – 365). The hour and day were transformed into sinusoidal signals by multiplying the hour or day ratio by π and then taking the sine of the resulting value. This transformation ensures that 0000 hours is as similar to 2300 as it is to 0100, preserving the cyclical nature of time. Additionally, we scaled all features using the Min-Max Scaler from the sklearn library to ensure they had equivalent ranges.

All models were implemented in Python 3.10 and trained on a Linux Ubuntu system with GPU capabilities. The LSTM model was developed using the Keras library, while the RF and LR models were implemented using the sklearn library. For the LSTM and RF models, we used the Optuna package for hyperparameter tuning. Optuna optimises the search for the best-performing parameters for each ML model.

As previously mentioned, our dataset included observations from the four stations covering the period from October 1, 2023, to November 30, 2023. We reserved the data for November 2023 (November 1, 2023, to November 30, 2023) for testing purposes. All training was conducted on data up to October 31, 2023, allowing us to evaluate the models on a full month of data. However, this approach also meant that training data was limited in some scenarios.

In the initial phase of our research, we focused on evaluating the effectiveness of AI models in scenarios with limited data by using only the observed data from the stations. For this experiment, we trained models for each target variable at each station using the following training sets:

- Data from October 1, 2023, to October 31, 2023, from the same station.
- Data from October 5, 2020, to May 11, 2023, from the Cirkewwa station.
- Data from October 1, 2023, to October 31, 2023, from the Cirkewwa station.

The goal was to evaluate the generalizability of models trained on data from different stations and to explore the feasibility of using longer datasets from other stations to improve model performance.

In the second phase of our research, we incorporated data from the ERA5 reanalysis to train our models. For each target variable at each station, we used the following training datasets:

- Data from January 1, 1940, to December 31, 2022, from ERA5.
- Data from January 1, 1940, to December 31, 2022, from ERA5, followed by fine-tuning with data from October 1, 2023, to October 31, 2023, from the same station.
- Data from January 1, 1940, to December 31, 2022, from ERA5, followed by fine-tuning with data from October 5, 2020, to May 11, 2023, from the Cirkewwa station.
- Data from January 1, 1940, to December 31, 2022, from ERA5, followed by fine-tuning with data from October 1, 2023, to October 31, 2023, from the Cirkewwa station.

This second set of experiments aimed to assess the viability of using a long-term reanalysis dataset to address the challenges associated with the scarcity of training data. By leveraging the extensive historical data from ERA5 and fine-tuning with more recent observations, we sought to improve the accuracy and robustness of the models.

Results

We trained and evaluated a total of 30 models for each target variable, resulting in a combined total of 120 models. Table 1 summarises the results obtained from these models, with Mean Absolute Error (MAE) used as the evaluation metric. To provide a more comprehensive overview, the MAE results for each model configuration were averaged across different stations.

Figure 2 illustrates the air temperature predictions for the Cirkewwa station made by the best-performing model from each of the different machine learning architectures. Figures 3, 4, and 5 follow a similar format: Figure 3 presents the wind speed predictions, Figure 4 the atmospheric pressure predictions, and Figure 5 the relative humidity predictions.

Discussion

Our results indicate that different meteorological parameters exhibit distinct characteristics and therefore require tailored modelling approaches. The simplest model, Multivariate Linear Regression (LR), performed the best for predicting air temperature and relative humidity. Notably, the LR model trained on the two-year Cirkewwa dataset produced the most accurate results for these parameters, even outperforming models trained on data from the station being evaluated. The Random Forest (RF) models trained on the ERA5 dataset and then fine-tuned using the two-year Cirkewwa dataset were the next best performers for both air temperature and relative humidity.

In contrast, for predicting wind speed and atmospheric pressure, the RF model trained exclusively on the ERA5 dataset (without fine-tuning) yielded the best results. This was particularly evident in the case of atmospheric pressure predictions, where the difference in performance between the ERA5-trained model and models not trained on ERA5 was significant.

Overall, our findings underscore the critical importance of having sufficiently large datasets. Our analysis suggests that models trained on extensive datasets from nearby stations, or using global datasets, tend to perform better than those trained on shorter datasets from the same station.

Another key observation from our results is that deep learning architectures, such as Long Short-Term Memory networks (LSTMs), should not be presumed to provide superior results automatically. We believe the primary reason for this is that the training datasets used in these experiments were smaller than what is typically required for deep learning models to achieve their full potential.

Table 1 – Mean Absolute Error values for each training set and each target variable averaged across all stations.

Training Set	Model	Air Temp. (deg. C)	Wind Speed (m/s)	Atm. Pres. (mbar)	Rel. Hum. (%)
Same Station (Oct 2023)	LSTM	3.994	2.505	5.660	9.603
	RF	4.347	2.375	4.934	8.671
	LR	2.839	8.164	3.587	27.734
Cirkewwa (2 yr)	LSTM	1.710	2.277	6.383	7.529
	RF	1.272	2.540	4.099	6.737
	LR	**1.192**	2.570	7.012	**6.195**
Cirkewwa (Oct 2023)	LSTM	4.253	2.576	5.997	9.572
	RF	5.010	2.989	5.531	8.702
	LR	2.547	5.707	3.447	16.264
ERA5	LSTM	2.238	2.913	5.624	17.680
	RF	1.593	**2.110**	**2.161**	15.614
ERA5 + Same Station (Oct 2023)	LSTM	2.890	2.892	4.946	9.024
	RF	4.339	2.469	4.903	8.450
ERA5 + Cirkewwa (2 year)	LSTM	2.114	3.047	5.042	7.577
	RF	1.242	2.616	4.237	6.691
ERA5 + Cirkewwa (Oct 2023)	LSTM	3.221	3.000	5.080	8.434
	RF	5.053	2.956	5.540	8.609

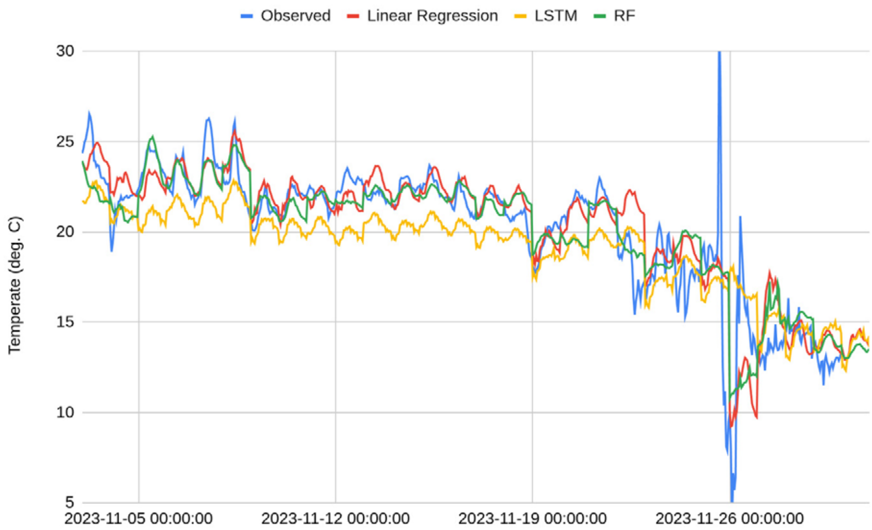

Figure 2 – Air Temperature predictions for the Cirkewwa station.

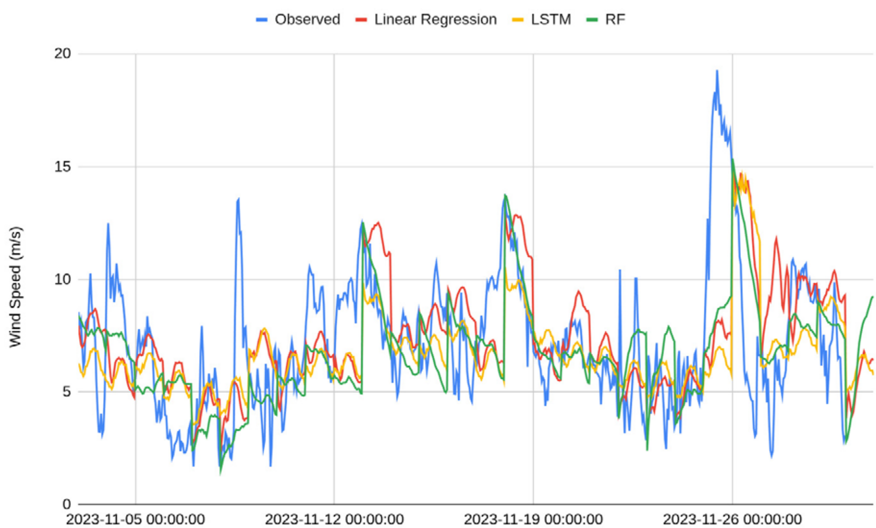

Figure 3 – Wind speed predictions for the Cirkewwa station.

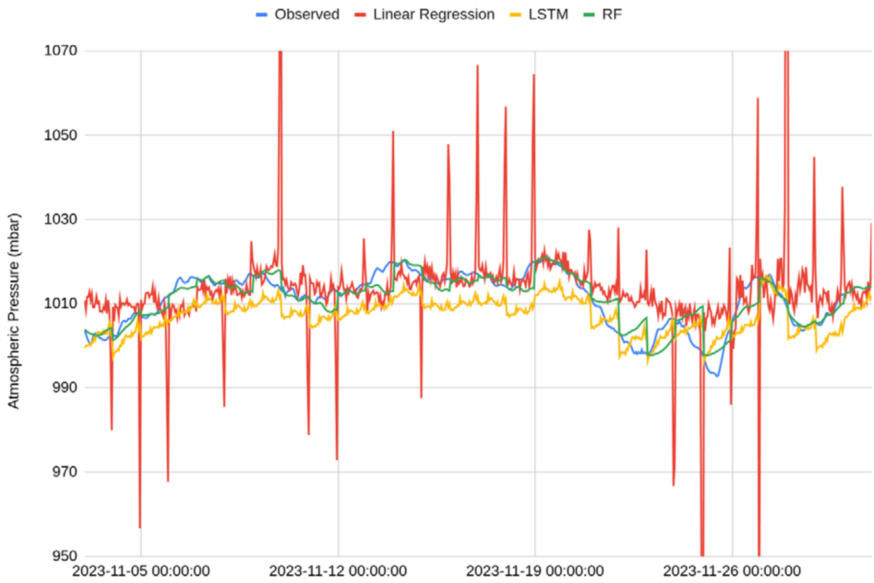

Figure 4 – Atmospheric pressure predictions for the Cirkewwa station.

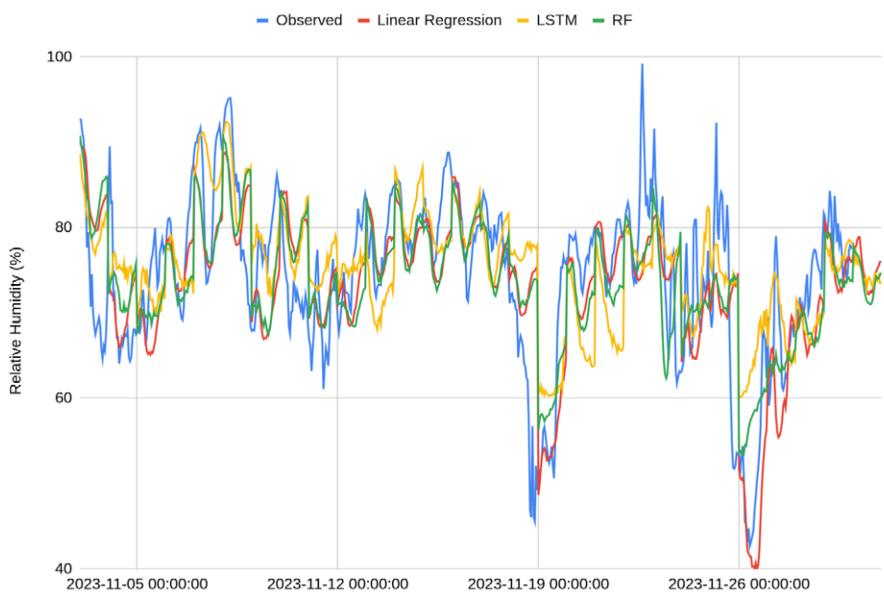

Figure 5 – Relative humidity predictions for the Cirkewwa station.

Conclusion

In this research, we explored the use of LSTMs, RF and LR to predict meteorological parameters based on observations from coastal meteorological stations. Our findings highlighted the critical importance of having sufficiently large training datasets. They suggest that models trained on extensive datasets from nearby stations or global models are preferable to those trained on shorter datasets from the same station.

For future work, we plan to investigate the effectiveness of pre-trained probabilistic forecasting models, such as Lag Llama [18]. Additionally, we intend to experiment with hybrid models that integrate AI with computational physical models, such as the WRF model, to potentially enhance prediction accuracy.

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PLASTIC POLLUTION ON THE TUSCAN COAST: ENVIRONMENTAL MEASURES MUNICIPALITIES CAN PUT IN PLACE TO REDUCE IT

Tosca Ballerini, Yuri Galletti, Daniela Tacconi

Abstract: Pollution by plastics and other chemical pollutants is outside of safe operating space of the planetary boundary for humanity. Scientific evidence shows that to address plastic pollution, it is urgently needed to deploy upstream interventions to reduce primary plastic production. In parallel to actions at the international and national level, municipalities can significantly limit single-use plastic pollution on their territory through the development of integrated strategies. Here, we show results of beach litter monitoring on three municipalities of the Tuscan coast, Tyrrhenian Sea, Italy. We identified environmental measures put in place by the municipalities to address single-use plastic (SUP) items and highlight further possible environmental measures to reduce plastic pollution at the local level.

Keywords: citizen science, environmental regulations, monitoring, plastic pollution, single-use plastic

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Tosca Ballerini, Yuri Galletti, Daniela Tacconi, *Plastic pollution on the Tuscan coast: environmental measures municipalities can put in place to reduce it*, pp. 858-871,
DOI: 10.36253/979-12-215-0556-6.74

Introduction

Pollution by plastics and other chemical pollutants is already outside of safe operating space of the planetary boundary for humanity [19]. The accumulation of plastic waste and associated toxic chemicals in the environment follows the increase of plastic production, which is projected to triple by 2060 under *business-as-usual* scenarios [15]. To address plastic pollution, it is urgently needed to reduce the production of primary plastic polymers [4]. In response to this crisis, the Fifth United Nations Environment Assembly (UNEA-5.2) adopted a resolution for a mandate to develop an internationally legally binding agreement by 2024 to end plastic pollution both in the marine and in the terrestrial environment considering the whole life cycle of plastics.

The European Plastic Strategy (COM/2018/028final) has set an aspirational reduction target of 30 % for marine litter and the Single-Single Use Plastics Directive (SUPD, 2019/904/EU) set out a goal for EU Member States to reduce the impact of certain single-use plastic products in the environment, by reducing or banning their use. The EU Marine Strategy Framework Directive (MSFD, 2008/56/EC) has the goal reach the Good Environmental Status (GES) of EU marine waters.

Beach litter is one of the indicators of the MSFD (D10C1.1) *"The composition, amount and spatial distribution of litter on the coastline [...] are at levels that do not cause harm to the coastal and marine environment*". It is easily detectable [12], correlates with the amount of marine litter, and has been successfully monitored worldwide through citizen science [26;30]. Data collected through citizen science can assist local decision-making [14]. Indeed, in parallel to actions at the international and national levels, municipalities can significantly limit plastic pollution on their territory through the development of integrated strategies [3; 32].

Here, we present results of beach litter monitoring, in three municipalities of the Tuscan coast, Tyrrhenian Sea, Italy, carried out between autumn 2022 and summer 2023 with the help of citizen scientists. We also present an analysis of the environmental measures to address pollution by single-use plastics (SUP) deployed by the three municipalities and suggest further possible actions to reduce this pollution at the local level.

Materials and Methods

Monitoring of beach litter items

Litter items were monitored on three beaches on the Tuscan coast, Italy, between November 2022 and July 2023 (Figure 1; Table 1). The sites are representative of different types of natural environment and all beaches are legally accessible by the public. At each site, a sampling unit was identified as a fixed section of the beach from the water's edge to the back of the beach of 100 m length. During the surveys, litter items were detected by visual observations and were removed (no digging to release litter buried in the sand, but litter items half under the sand were retrieved). Litter items were counted and categorized according to the *Joint List of Litter Items* developed by the MSFD Technical Group on Marine

Litter distinguishing 183 item categories grouped by 9 material types [9]. Data were reported as number of litter items / 100 m survey and were aggregated at different temporal / spatial scales using the median, the preferred calculation method to aggregate data to assess EU marine beach litter baselines [13]. The top 10 most abundant litter items for each site and the top 20 litter items across all surveys were identified by lumping together the items over the different measurements and presented as fraction of the total litter items. Overall, 55 volunteers were trained and took part in the surveys. The authors of the paper supervised the final classification of beach litter items, transcribed the field work data in an electronic spreadsheet and compiled the associated meta-data.

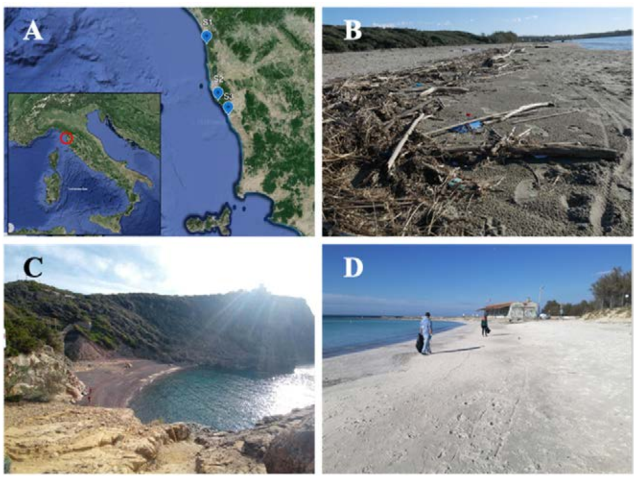

Figure 1 – Map of the Tuscan coast (A) and the three study sites: S1 – Bocca di Serchio (B), S2 – Cala del Leone (C), Lillatro (D).

Environmental measures to address SUP items by municipalities

Three in-presence and two online meetings were carried out with the environmental councilors of the three municipalities to illustrate the results of the beach monitoring and discuss the environmental measures that municipalities have already deployed or can put in place in the future to address plastic pollution. In April 2024 a questionnaire was provided to the councilors asking them which environmental measures had been put in place in their municipality. Questions were taken from a report of guidelines for municipalities on how to reduce plastic waste from SUP single-use items developed by the regional branch Emilia Romagna of the National Association of Italian Municipalities (ANCI Emilia Romagna) [2]. A first set of questions regarded "Measures to reduce single-use products in different policy areas" grouped under different areas of intervention. A second set of questions "Behaviors to be promoted and related measures" included 8 behaviors with associated target flows, target scopes, and the main measures that the municipalities can put in place. Councilors were asked to evaluate each environmental measure on the base of a Plus, Minus, Interesting (PMI) analysis [23] listing, respectively, all the advantages (PLUS), disadvantages (MINUS), and anything that needs future investigation (INTERESTING). On May 2024, a workshop on the role of municipalities on the environmental transition was carried out and the guidelines for municipalities on how to reduce waste from single-use items were presented in details by their lead author [2]. A SWOT (strengths, weaknesses, opportunities, and threats) analysis on the implementation of environmental measures by municipalities to reduce plastic pollution was then carried out.

Table 1 – Abundance of litter items on the three survey sites along the Tuscan coast.

Site	Location	Description of sampling site	Date	Abundance (items / 100 m survey)
S1	Bocca di Serchio (Marina di Vecchiano)	Sandy beach close to the river mouth of the Serchio River, inside the park of Migliarino San Rossore Massaciuccoli.	05/11/22	1266
			26/03/23	1266
			05/06/23	1121
S2	Cala del Leone (Livorno)	Small bay with pebbles. Free beach, not equipped.	01/11/22	438
			02/04/23	1191
			23/06/23	1471
S3	Lillatro (Rosignano)	Sandy beach with an anthropized dune system, close to a beach resort. Partially equipped in the summer period.	13/11/22	1526
			25/02/23	2354
			14/07/23	604

Results

Abundance and types of beach litter items

A total of 11 237 litter items were collected and categorized for a median litter abundance of 1266 items / 100 m (Table 1, Figure 2). A total 126 item categories were found and of these 55.13 % were items of undefined use. Litter items made of artificial polymers represented the majority of items in total (88.39 %: Figure 2) and at the three sites (S1: 96.47 %; S2: 78.45 %; S3: 88.67 %; Figure 3D). Litter items in paper and carboard and litter items in metal corresponded, respectively, to 3.42 % and 3.14 % of total litter items. Other materials were represented by less than 2 % (Figure 2). Litter items featuring in the top 10 across all surveys correspond to 79.44 % of total litter items, while litter items featuring in the top 20 across all surveys correspond to 89.04 % of total litter items and six of them are single-use plastic (SUP) products according to the SUPD (14) (Figure 2). They are: cigarette butts (22.69 %), plastic drink bottles (4.38 %, all sizes together), plastic caps/lids drinks (2.89 %), plastic cotton bud sticks (2.79%), plastic crisps packets/sweets wrappers (1.61 %) (Figure 2). Overall, SUP items correspond to 36.96 % of the total litter items.

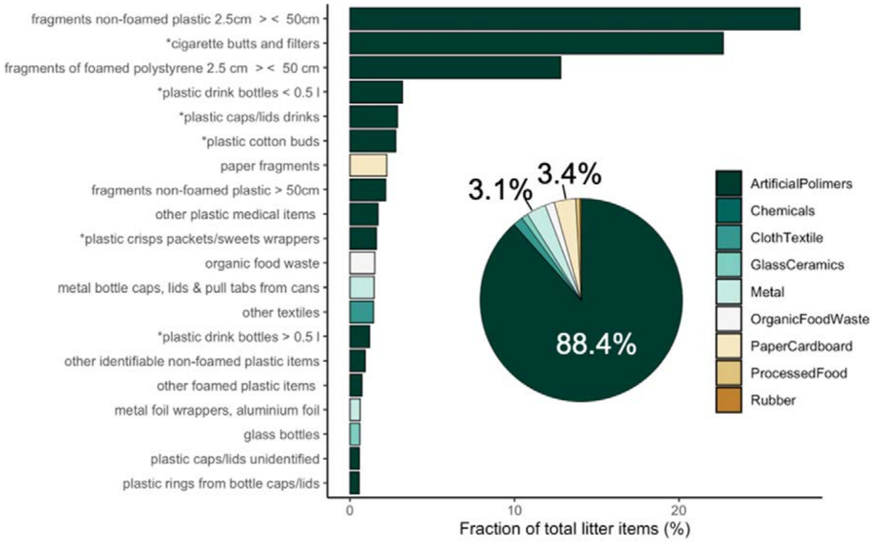

Figure 2 – Top litter items and materials found on Tuscan beaches between 2022 - 2023. Top 20 litter items are shown as fraction of the total. Percentages <2% are not shown. The symbol "*" indicates SUP items.

The highest abundance of litter items was found at S3 (range: 604 ÷ 2354 litter items / 100 m survey), followed by S1 (range: 1121÷1266 litter items / 100 m survey) and S2 (range: 438– 1471 litter items / 100 m survey) (Table 1). At S1, the top 10 litter items over the three surveys (85.98 % of the total) were all artificial polymers (Figure 3A). SUP items were found at each sampling occasion, and plastic cotton bud sticks were the most abundant (310 items during the first survey, and 59 items at the third survey). At S2, the top 10 litter items over the three surveys correspond to 79.71 % of total items (Figure 3B). SUP items were found at all sampling occasions, and the most abundant were cigarette butts with filters (35, 0, and 571 items respectively during the first, second and third surveys), plastic drink bottles ≤ 0.5 l (2, 3 and 300 items, respectively, during the first, second and third surveys), plastic drink bottles > 0.5 l (58, 34, and 16 items respectively at the first, second, and third survey). During the third survey, 49 glass bottles were found. At S3 the top 10 litter items over the three surveys corresponded to 89.72 % of total (Figure 3C). SUP items were found in each sampling occasions, and cigarette butts with filters were the most abundant (1040, 430, and 317 items respectively during the first, second, and third survey). Litter items collected in the watershed of Serchio River and discharged at its river mouth are probably the most abundant source of litter items at S1, while at S2 and S3 the main source of litter items is likely related to coastal-based tourism and recreation at S2 and S3).

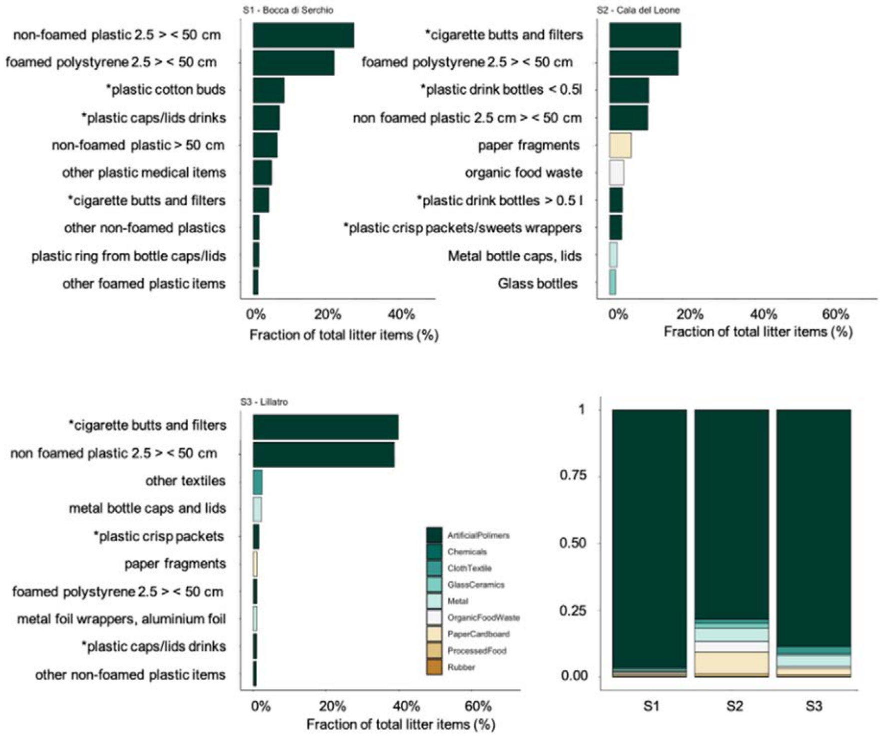

Figure 3 – Top 10 litter items and materials at S1 (A), S2 (B), S3 (C) and litter composition (D) on the three sites on Tuscan beaches between 2022 - 2023. Top 10 litter items are shown as fraction of the total. Percentages <2 % are not shown. The symbol "*" indicates SUP items.

Environmental measures by municipalities

Results of the questionnaire (Table 2) show that for what concerns the "Measures to reduce single-use products in different policy areas", only 13 out of 45 possible measures listed in [2] have been put in place by at least one municipality in 6 out of 10 policy areas, while for what concerns the "Behaviors to be promoted and related measures", out of 28 possible measures only 7 have been implemented by at least 1 municipality to promote 5 out of 7 behaviors listed in [2]. As part of actions aimed at reducing plastic pollution and promoting sustainability, the municipality of Livorno put in place Ordinance No.256 of 26/07/2019, Ordinance No. 260 of 30/07/2019, and Ordinance No. 7 of 14/01/2020 that include provisions to prohibit the marketing and use of "non-biodegradable" disposable containers and tableware on beaches and at fairs and festivals, in parks, and at sporting events, respectively. The municipality of Rosignano Marittimo put in place Ordinance No. 319 of 24/07/2019 that bans single-use plastic objects on beaches. It also approved the "Regulation governing the conduct of temporary commercial initiatives (markets) and other particular concessions for temporary sales on public areas - updated 16/09/2021" that includes the obligation to use disposable material (plates, glasses, cutlery, etc.) exclusively of the "biodegradable and/or compostable type" and "Regulation for the environmental management of food and drinks during temporary initiatives and festivals - updated 16/09/2021", which includes the ban on single-use plastic and glass bottles, obligation to use reusable drink containers or tap water; the ban on the distribution of packaged single-serving products such as cakes, yoghurt, desserts; the obligation to use reusable tableware (plates, cutlery and glasses) and/or "biodegradable thermoplastic materials".

Table 2 – Environmental measures put in place by at least one municipality.

Policy areas
Municipal offices: Removal of PET water bottles from meetings and replacement with reusable bottles or tap water; Installation of water fountains.
Events, conferences, public events organized at municipal facilities: Water fountains.
Shows, festivals and events on public land: Water fountains; Washable crockery and dishwasher kit rental service
Schools and universities including school catering service: Training and awareness-raising; Invitation to use own water canteen/bottle; Installation water fountains; Promotion of mid-morning fruit and backed goods as a substitute for packaged products.
Retail activities (small and large-scale distribution): Communication/awareness-raising, measures to promote reduction of single-use products (but allowing "biodegradable plastics")
Citizens and visitors/ tourists: Communication/awareness-raising (cigarette butts and litter); Reusable tableware rental service for small events.
Behaviors to be promoted
Use of reusable shopping bags: Awareness-raising activities
Use of reusable crockery and glasses at home, private parties: Reusable crockery and glassware rental service
Use of reusable crockery and glasses for events / festivals: Awareness raising
Use of reusable glasses and tableware in schools: Awareness raising; water fountains; distribution of reusable water bottles
Use of tap and reusable tableware: Water fountains

Discussions carried out during the May 2024 workshop allowed to identify some lack of specific-in house expertise, in particular regarding "biodegradable plastics" and at the request of councilors, scientific information was shared about their characteristics and their environmental impacts. The councilors highlighted the difficulties in ensuring citizens' compliance to existing regulations in face of lack of resources. For example, Rosignano Marittimo had approved the "Municipal Council Resolution No. 273 of 19/09/2019 - Approval of guidelines concerning the protection of public health, aimed at banning smoking and littering of smoking products on municipal beaches" but the resolution was never transformed in administrative act because of difficulties to enforce it. The environmental councilor of Marina di Vecchiano highlighted the lack of resources in terms of technical personnel and expertise in small municipalities. Councilors also highlighted the challenges for an effective communication with citizens. There was common agreement on the opportunity to promote collaboration with local stakeholders (universities, research centers, NGOs) and promote future citizen science projects to enhance citizens' education and awareness. These considerations have been included in the SWOT analysis (Table 3).

Table 3 – SWOT (strengths, weaknesses, opportunities, and threats) analysis for the implementation of environmental measures by municipalities to reduce plastic pollution.

Strengths	**Weaknesses**
Direct regulatory power to implement local regulation and policies that can lead to significant changes; Setting plastic free and single-use free public procurement policies, targeted supplier requirements and contracts; High level of community and associations involvement and participation; Collaboration with local universities and research centers; Engagement in citizen science projects and citizens' education and awareness; Experience in EU project (Livorno as cascade city – Horizon 2020).	Lack of specific in-house expertise able to define effective strategies; Lack of resources; Lack of a structured system for coordinating stakeholder participation (working groups); Difficulties in ensuring citizens' compliance the existing regulations; Challenges to effective communication with citizens.
Opportunities	**Threats**
Join forces among municipalities to build critical mass and create greater synergies in reducing the use of single-use products; Municipalities as governance network actors through the involvement of ANCI Toscana; Establishment of living labs for the development and monitoring of pilot actions, which will serve as models for other coastal cities; Regional, national and European funds; New opportunities and engagement of young people; Lower environmental and social costs associated with waste generation.	Economic system still oriented towards use-and-throw-away rather than reuse and circular and regenerative models; Italian regulatory framework in partial contrast to EU directives and actions to reduce single-use products; Danger of "regrettable substitutions" (the change from a known hazardous to not-yet-known hazardous substance) [10]; Conflicts with specific categories of stakeholders could compromise the social contract with some of them delaying policy implementation.

Discussion

Abundance of SUP items higher than the EU marine litter threshold

To achieve or maintain a Good Environmental Status (GES), the MSFD Technical Group on Marine Litter set the threshold value for beach litter at 20 litter items /100 m beach length, considered as a value able to reduce harm from beach litter to a sufficiently precautionary level [28]. This value was largely surpassed in all surveys in this study, in which 88.39 % of the litter items were artificial polymers, and 36.96 % of all litter items were SUP items for which reduction or banning prescription exist according to the SUPD. Despite difficulties in comparing abundance of litter items with other locations due to inhomogeneity in the sampling methods [5], the median beach litter density reported here (1266 items / 100 m) is higher than in precedent surveys along the Tuscan coast (603 items / 100 m in the period 2020 – 2021 [8]), the Tyrrhenian Sea (491 items/100 m between 2015 - 2018; [11]), and at the level of the Western Mediterranean Sea (196 and 255 items / 100 m survey in 2015 and 2016, respectively Hanke et al.). In this study we detected a higher contribution of artificial polymers over total litter items in comparison to the Italian coastline in the period 2015 – 2018 (74 % [11]) and a value comparable to European beaches between 2015-2021 [85 %; 26].

Temporal series on macrolitter abundance are important to evaluate through time the effectiveness of the implementation of existing environmental regulations. Beach litter density estimates gathered in this study are the firsts available for the three beaches and additional surveys in the future will allow to gather baseline values estimates with adequate precision to be able to detect changes of macrolitter abundance in time [22]. For the assessment of accumulation and loading rates during regularly repeated surveys no clean ups should occur on the sampled site between two monitoring surveys [12]. However, partial clean ups by beach users occurred between the second and the third survey at S2 and S3, thus the data reported here represent a low-end estimate of accumulation and loading rates on the Tuscan coast over the study period.

The SUPD has been transposed in the Italian legislation with the Legislative Decree n. 196 of 8 November 2021 that came into force on 14 January 2022, respectively 10 and 18 months before the first (November 2022) and last survey (July 2023) of this study. The most abundant SUP items found on this study (cigarette butts, drink bottles and associated caps/lids drinks, cotton bud sticks) were also among the most common litter items found on a large-scale monitoring though citizen engagement carried out on Italian beaches on May 2023 [16].

Cigarette butts

Cigarette butts and their chemical components are toxic to invertebrate and vertebrate marine organisms [24]. Since the 1980s, they have consistently been the largest single type of litter by count worldwide [2017]. They represented 20.9 % of litter on European beaches between 2015-2021 [26] and 22.69 % in this study. The resolution from smoke-free beaches by the municipality of Rosignano Marittimo, where the highest abundance was found in this study, never came into force because of anticipated difficulties in its implementation. However, smoke-free beaches exist in the USA, Australia, Canada, and Spain [27]. In Italy, the first smoke-free beach was introduced on the coast of Bibione in 2014 [6] and smoke-free beaches have now been created in more than 15 municipalities [29].

Cigarette butts are included in Part E of the Annex of the SUPD (Section III "Other single-use plastic products referred to in Art. 8(3) on extended producer responsibility") that requires Member States to ensure that producers cover at least the costs of awareness-raising measures, removal of waste from these dispersed products and the subsequent transport and treatment, and data collection and reporting. The majority of EU Member States copied and pasted this list of costs in transposing the SUPD in their national laws, but the Legislative Decree n. 196 of 8 November 2021 differs for the inclusion of a precision indicating that the costs are to be established in proportion to the weight of the plastic component in relation to that of the product [25]. The Decree also says that "*In order to make consumers aware of the harmful environmental consequences of abandoning cigarette butts, manufacturers, in cooperation with the Ministry for the Environment, Land and Sea, implement information campaigns*". This provision is in breach of Article 5.3 of the WHO Framework Convention on Tobacco Control (to which the EU and each Member States are parties) who recognize a fundamental and irreconcilable conflict of interest between the tobacco industry and public health and environment, and according to which manufacturers should not take part in organizing awareness-raising measures [25].

To promote the application of the extend producer responsibility, reduce littering of cigarette butts and associated pollution, municipalities could promote the development of deposit return systems (DRS) similar to those for single-use drink containers (see below) in which cigarettes could be sold with a "butt deposit" to be refunded when the butts are returned to the vender or to a hazardous waste disposal facility [18].

Drinks bottles and caps/lids

The SUPD prescribes Member States to achieve selective collection rates of PET bottles of 75 % by 2025 and 90 % by 2029, either by establishing DRS or through separate collection targets for relevant extended producer responsibility schemes (Art. 9 "Separate collection"). A DRS place a small deposit on beverage purchases, which is refunded when the empty container is returned for recycling (DRS for recycling) or for reuse (DRS for reuse). In well-designed DRS, producers have the operational and financial responsibility of the system and fines apply if collection targets are not met. The new Packaging and Packaging Waste Regulation (PPWR), expected to entry into force in the last quarter of 2024, prescribes mandatory DRS for recycling by 2029 for plastic bottles and metal cans if a selective collection rate of 90 % is not achieved. Currently, DRS systems for recycling are in place in 16 countries in Europe with an average collection rate for PET bottles > 94 % compared to 47 % for European countries without a DRS [21].

In Italy, the introduction of a DRS for recycling would results in an increase of the separate collection rate from current 73.4 % to 95.3 % for PET bottles, from 89.6 % to 96.0 % for metal cans, and from 80.6 % to 95.8 % for glass bottles [7]. The association Comuni Virtuosi promoted a national campaign - sustained by major Italian NGOs, the Italian Society of Ecology (SITE) and several municipalities - to ask the Italian government to develop a DRS for recycling that includes plastic drink bottles, metal cans, and glass bottles [1]. While DRS systems need to be implemented at the national level, municipalities can help the promotion of reusable containers [3], as done by Rosignano Marittimo that banned single-use drink containers and promoted the use of reusable drink containers at events and festivals. The ban could be extended to other situations and to other single-use packaging.

Plastic cotton buds

Cotton buds are often flushed down toilets instead of being put in the bin and due to their size and shape end up in the marine environment via overflow events when wastewater is released with little treatment and through some treatment tanks due to the difficulty in identifying and retaining small litter items [11]. Together with plates, cutlery, straws and balloon sticks, they are listed on Part B of the SUPD's Annex ("Single-use plastic products covered by Article 5 on restrictions on placing on the market"). Since 3 July 2023 all these products are banned on EU Member States, but they are still available for sale in Italy. Cotton buds have first been regulated in Italy by Law n. 205 of 27 December 2017 which required mandatory labeling about correct disposal and banned from January 1st 2019 all cotton bud sticks made of plastic material not conform with UNI EN 13432:2002, the Italian standard corresponding to the European EN 13432:2000 standard for compostability. An evaluation of effectiveness of Law n. 205 carried out on the Tyrrhenian coast from winter 2019 to winter 2020 showed that it did not lead to a reduction in the amount of cotton buds entering the marine ecosystem, with cotton buds still being the most abundant litter item (42.3% of total litter items [20]).

For what concerns the other SUP items listed in Part B of the SUPD's Annex, the perimeter of application of Legislative Decree n. 196 of 8 November 2021 allows them to be placed on the market if made of plastics that comply with the UNI EN 13432:2002 standard, thus in contradiction with the SUPD which applies to all artificial polymers. This is one of the reasons at the base of the decision of the European Commission to open an infringement procedure on 23/05/2024 by sending a letter of formal notice to Italy (INFR(2024)2053) in which it commented that "*Italy has failed to transpose, or to transpose correctly, several provisions of the Single-Use Plastics Directive into national law, which affects its scope and application*".

While acknowledging that targeted applications have shown some benefits, the EU Plastics Strategy points out that "*it is important to ensure that consumers are provided with clear and correct information, and to make sure that biodegradable plastics are not put forward as a solution to littering*". As well as most other plastic biodegradation standards, the EN 13432:2000 standard relies on laboratory tests and/or relate to degradation in industrial facilities in which temperature is expected to reach 70°C [40], conditions which are not relevant when the plastics are used or disposed of in natural environments. "Biodegradable plastics" also contain toxic chemicals and while their degradation is accelerated during composting (high temperature, moisture, microorganisms), it is much lower in the soil or in the ocean, leading to the additional release of toxic chemicals, and also of micro- and nano-plastics [17].

The role of municipalities in addressing plastic pollution

Municipalities can significantly limit plastic pollution on their territory through the development of integrated strategies that include public procurement, exemplarity, territorial animation, and by banning the use of certain products on their territory [3; 32]. They can also promote business that voluntarily decide to reduce the use of single-use packaging [3], thus preventing plastic waste generation. Strategies by municipalities to reduce plastic pollution also include the promotion of the consumption of tap water; the improvement of wastewater and stormwater management infrastructure to preserve the water cycle from plastic pollution; the improvement of the collection and recycling of plastic wastes [32]. Clean ups, while not a solution to littering and plastic pollution as they act downstream from the problem, have the advantage of making people aware and allow collecting data useful for steering local strategy [32].

As shown by the promotion of single-use tableware made of “biodegradable plastic” by two of the municipalities on the Tuscan coast, however, the lack of specific in-house expertise and the fact of being immersed in the Italian regulatory framework which is in partial contrast with the SUPD and does not take into account scientific evidence hinders the capacity of municipalities to define effective strategies and poses the risk of promoting “regrettable substitutions” [10].

Conclusions

We provided the first quantitative assessment of beach litter on three beaches of the Tuscan coast showing levels of plastic pollution among the highest at the Mediterranean level. We gained an overview of the environmental measures put in place by the three municipalities, identifying the barriers and opportunities associated with implementing circular strategies to limit plastic pollution. On one hand, municipalities have the power to significantly limit plastic pollution through the development of integrated strategies and targeted regulations (Strengths); on the other, they face a lack of resources and knowledge (Weaknesses) and find themselves in an Italian regulatory framework in partial contrast with the EU Single-Use Plastics Directive and not promoting actions to reduce single-use products (Threats). Despite the strong connection of municipalities with the territory, the weaknesses and threads that have been identified hinder the transition of cities towards circular consumption models, which promote reuse and regeneration systems over disposable ones. However, we believe that the creation of synergies free of conflicts of interests among municipalities, research institutes, local associations, and citizens can lead to tangible results to reduce plastic pollution, while helping in the acceptance of environmental regulations by citizens (Opportunities).

Acknowledgments

This work was carried out in the framework of the project *Profili Antropici*, financed by “8 per Mille Chiesa Valdese”. We thank the volunteers of *Semi di Scienza* and *Sons of the Ocean* who participated in the monitoring; the environmental councilors M. Canarini, G. Cepparello, and V. Brogi for their availability and collaboration throughout the project; P. Azzurro for presenting the guidelines for municipalities on how to reduce waste from single-use items.

Author Contributions

Conception, design of the study, and methodology (TB); training of volunteers (TB, YG, DT); investigation (TB, YG, DT); formal analysis and writing - original draft (TB); writing - review and editing (TB, YG, DT); resources and project administration (YG). The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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NETWORK ANALYSIS OF MARINE LITTER IMPACTS ON COASTAL ECOSYSTEMS

Montserrat Compa, Antoni Sureda

Abstract: There is an increase in reporting of marine litter in coastal ecosystems globally, especially in recent years. A literature review was carried out to identify the primary impacts and effects its presence may have on coastal ecosystems worldwide. Various search combinations in the search engine SCOPUS were performed considering 'impacts', 'effects', 'marine litter', 'marine debris', and 'coastal', for a total of 939 studies. Studies considered were published from 1974 to 2024 and an important increase in publications was observed over the last decade, especially for scientific articles. Next, search terms for three categories of predefined impacts and effects were used to identify the main research directions and emerging areas of interest within coastal marine litter research. Overall, this study highlights the focus and trends of current marine litter research globally.

Keywords: coastal health, marine litter, literature review, network analysis

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Montserrat Compa, Antoni Sureda, *Network Analysis of Marine Litter Impacts on Coastal Ecosystems*, pp. 872-880, DOI: 10.36253/979-12-215-0556-6.75

Introduction

Marine litter is defined as any persistent, manufactured, or processed solid material discarded, disposed of, or abandoned in the marine and coastal environment [1] and is ubiquitously found in global oceans and seas, from the sea surface to the sea floor and especially on coastlines. This has extensively been addressed in several international policies such as the United Nation’s sustainable development goal 14 Life Below Water where plastic pollution is one of the top five state of emergency actions that need to be addressed in addition to acidification, ocean warming and overfishing [2] and the Marine Strategy Framework Direction Descriptor 10 which indicates that properties and quantities of marine litter do not cause harm to the coastal and marine environment [3]. Recent estimates indicate the total amount of buoyant marine plastic litter is 3000÷3400 kilotonnes, which is much higher than previous estimates, while the plastic input into the marine environment is 470–540 kilotonnes per year, slightly less than previous estimates [4].

Over the last several decades, there has been an increase in literature reporting the various impacts and effects that marine litter has on the marine environment and its significant threat to coastlines. This includes beaches [5, 6, 7] and estuaries [8, 9, 10], in addition to reports of the presence of litter that can transport hazardous pollutants associated with marine litter, potentially affecting biodiversity and harming ecosystem health. Negative impacts on wildlife, such as ingestion and entanglement, have been reported on a wide range of species, including fish [11, 12], seabirds [13], sea turtles [14], and marine mammals [15], among others. In addition to environmental concerns, there are several economic costs to marine litter that, in turn, can affect tourism [16] and fishing industries through gear loss [17]. Human health risks, from ingestion of contaminated seafood to human exposure and toxic effects, add further urgency to address this widespread issue [18, 19, 20]. Understanding key factors is necessary to develop comprehensive efforts, including improved waste management, public education, and policy interventions, in addition to a more drastic shift toward more sustainable practices.

Using keyword search terms for network analyses in studying marine litter on coastlines is an effective approach as can capture the diverse and complex nature of the problem. Marine litter, which includes various solid objects such as plastic bottles and fishing nets, has numerous sources and impacts that keywords can help identify and categorise. Keywords such as "marine debris," "plastic pollution," and "fishing gear waste" allow for a comprehensive dataset collection, ensuring that all relevant aspects are covered. This approach helps identify the specific impacts on different coastal environments, such as beaches and mangroves, as well as the threats to wildlife from entanglement and ingestion. Economic and social implications, such as the decline in tourism and fishing industry impacts, can be traced using terms like "economic costs" and "tourism decline." Keywords also facilitate the understanding of other impacts, such as the spread of invasive species, public health concerns, and the aesthetic and recreational value of coastal areas. Moreover, they help to explore policy and management strategies by highlighting terms such as "waste management" and "public awareness." A previous study by Liu et al. (2023) [21] identifies how network analyses are useful to understand the toxicological implications of microplastics and nanoplastics in soil. By mapping relationships and interactions between these aspects, network analyses can reveal key nodes and links between the co-occurrences of keywords, providing insights into priority areas for intervention. This structured exploration helps in formulating targeted and effective solutions, making the use of keyword search terms a robust method to understand and address marine litter on coastlines.

In this study, we review and analyse the major impacts of marine litter on coastal ecosystems around the world that have been observed historically over the previous half century. The main objective of this study is to (i) provide a synthesis of the current impacts of marine litter on coastal ecosystems and (ii) perform a methodological review of previous research highlighting the important insights from studies.

Materials and Methods

The following search terms were used in the search engine SCOPUS on March 17, 2024: 'impacts AND marine AND litter AND coastal' OR 'impacts AND marine AND debris AND coastal' OR 'effects AND marine AND debris AND coastal' OR 'effects AND marine AND litter AND coastal'. A total of 939 studies were returned. The search was performed in unison to avoid duplicates. From here, important information such as year of publication, types of publications and the top journals were analysed to provide a descriptive analysis.

In this study, we used the litsearchr package R [22], which was created to facilitate reproducibility and transparency, to identify the main direction research in moving towards. To achieve this, two network analyses were performed; the first used keywords and the second network analysis used search terms for three groupings of impacts and effects of marine litter. For the first network analysis, keywords served as nodes or attributes, helping to map connections between different types of litter, their sources, and impacted areas. To complete this, we used the author's keywords that were reported in each study. For the inclusion of a keyword, the relevant search terms had to be included at least twice. Then all the abstracts were searched for the incidence of the selected keywords. From this, a network analysis was performed to determine linkages between search terms. For the second network analysis, to determine terms of impacts and effects, we follow Agamuthu et al. (2019) [23] for their descriptions of impacts and effects summarised into three categories: injury to or death of marine organisms, harm to the marine environment and effects on human health and economy. Finally, the results from the search term network were graphed to determine the possible links between the search terms.

Results and Discussion

A literature search was carried out to identify the impact of marine plastic pollution that affects coastal ecosystems worldwide. Various search combinations in SCOPUS were performed considering 'impacts', 'effects', 'marine litter', 'marine debris', and 'coastal', for a total of 939 studies. The results from the search data are presented in Figure 1A and highlight the trend in publications on the impacts and effects of marine litter in coastal environments. The studies considered were published from 1974 to 2024, with an exponential increase over the past decade, an indication an increase in the interest in researching and/or reporting in this field. A slow and steady increase in reporting was observed the first decades, followed by the rapid and exponential growth of the more recent years, which is indicative of the growing understanding of the importance of researching the negative effects of marine litter on coastal ecosystems. The rise in publications highlights a growing focus on addressing marine litter and developing strategies to mitigate plastic contamination and promote marine health worldwide. Regarding the types of publications from the past 50 years, the majority are scientific research articles (78%) followed by reviews (9%), conference papers (7%) and book chapters (5%) (Figure 1B). There were other types of publications (conference review, data paper, erratum, note, book, and short survey) which all represent less than 1% of the publications.

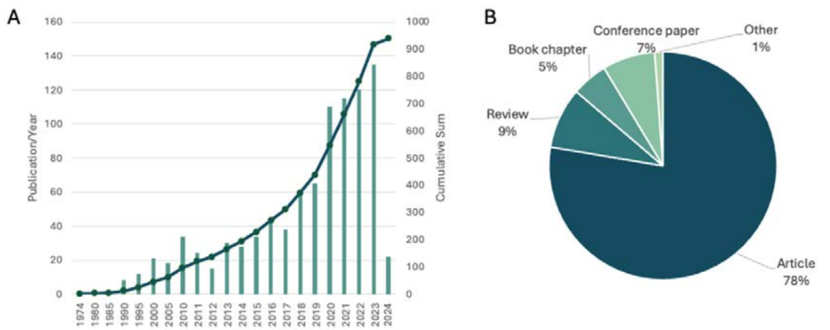

Figure 1 – Summary of the results from the literature by A) Annual scientific production from the Scopus search results containing the keywords for impacts of marine litter on coastal areas barplot (publications year) and a scatterplot on the second axis for the cumulative sum of publications, B) pie chart for the percent of each type of article classified by research article, review, conference paper, book chapter, and other types of articles.

In regarding the top ten journals where publications from our search terms were located, Marine Pollution Bulletin, Science of the Total Environment and Environmental Pollution were the top three journals (23 %, 8.3 % and 4.7 % respectively) (Table 1). Next, we report the h-index according to SCImago Journal Rank (SJR), which is a journal's number of articles (h) that have received at least h citations over the whole period. In general, the h-index ranged from 48 to 353 (Table 1). Regarding the top publishers, the three most predominant journals have the highest h index according to the SJR, Marine Pollution Bulletin (h-index = 229), and Science of the Total Environment (h-index = 353), and Environmental Pollution (h-index = 301). Moreover, the Impact Factor for each of the journals presents the measures for the average number of citations received in a particular year by papers published in the journal during the two preceding years according to the Journal Citation Reports, and for this study, we opted for the Impact Factor (IF) determined for the year 2022. For the studies published during the time frame, the IF ranged from 0.42 to 9.8 (Table 1). The journals with the highlight IF were Science of the Total Environment (IF = 9.8), Environmental Pollution (IF = 8.9), Marine Pollution Bulletin (IF = 5.8), and Environmental Science and Pollution Research (IF = 5.8). Overall, these results give insight into main journals where scientific results are being presented on the implications of marine litter in coastal environments.

Table 1 – Top 10 journals returned from the search to determine the impacts and effects of marine litter on coastal environments.

Journal	Number of Studies	% Publications	h-Index	IF (2022)
Marine Pollution Bulletin	220	23.4	229	5.8
Science of the Total Environment	78	8.3	353	9.8
Environmental Pollution	44	4.7	301	8.9
Frontiers in Marine Science	23	2.4	101	3.7
Ocean and Coastal Management	19	2.0	107	4.6
Marine Policy	13	1.4	123	3.8
IOP Conference Series: Earth and Environmental Science	11	1.2	48	0.42
Marine Environmental Research	10	1.1	111	3.3
Marine Geology	10	1.1	159	2.9
Environmental Science and Pollution Research	9	1.0	179	5.8

In Figure 2A, we can observe the results from the network analysis of the keywords observed throughout all the abstracts of the publications from the literature search with the top keywords being 'marine environment', 'plastic debris' and 'marine debris' being the top keywords. Here we can observe that the terms that appear near the centre are linked to each other by darker lines, an indication of increased importance regarding marine litter research in coastal areas, such as 'marine plastic', 'coastal areas', and 'fishing activities'. While search terms that appear in the outside margins of the graph with very faint green lines indicate that they are not as closely related to the other search terms or the co-occurrence was not very common, such as ‘Gulf of Mexico’, ‘intertidal zone’ and ‘blue carbon’, which are more targeted features. This also highlights areas where future research is needed, such as coastal wetlands and coastal dunes, or specific sentinel species like the loggerhead turtle, as well as other endangered species. These results highlight that despite a growing amount of research in this field, there are still many gaps into the impacts and effects marine litter has on coastal habitats and ecosystems.

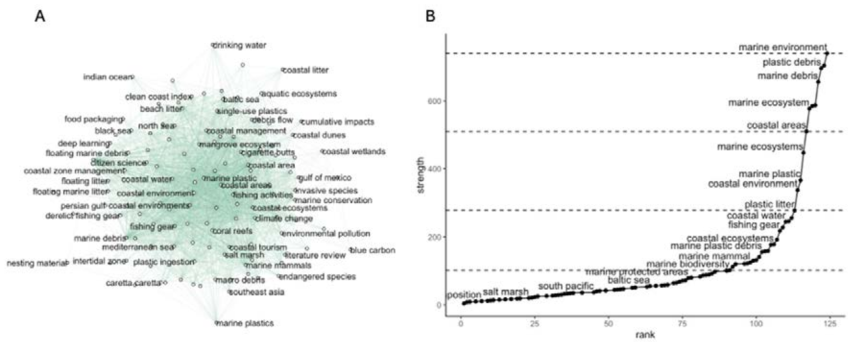

Figure 2 – Network analysis of the indexed keywords (A) and ranking of the most keywords based on strength (B). Horizontal lines are the cutoff points.

The next and final step in the network analysis for keyword search terms, was to rank the terms by importance by determining the strength of each term. This is defined as the number of other terms each of the search terms appears with and ranked in ascending order and establishing cut-off points or changepoints, where the strength of the next strongest term is much greater than that of the previous one (places where the ascending line ‘jumps up’). In Figure 2B we can observe 4 cut-off points just before the strength of the term increases. In terms of sources, we can observe that fishing activities and fishing gear are both potential sources in addition to being affected by marine litter through economic impacts, which are reported in the literature. Moreover, we can observe specific locations globally where an increase in marine litter research is occurring, specifically in the south Pacific and the Baltic Sea.

For the second evaluation, a network analysis was performed to determine the presence of the target search words within the three categories for impacts and effects. Here, the abstracts were searched and for the inclusion of a keyword present at least twice. In terms of the category of injury to or death of marine organisms, a total of 38 search terms were defined, and the results indicated 425 studies included these terms. In Figure 3A, we can observe a high co-occurrence between ingest-entanglement, ingest-organisms, and organism-toxic.

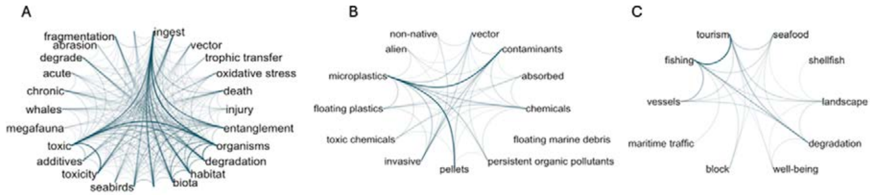

Figure 3 – Results from the network analysis for: A) injury or death to marine organisms, B) harm to the marine environment and C) effects on human health and economy.

Regarding the harm to the marine environment (Figure 3B), a total of 17 search terms were used, which resulted in the selection of 253 studies. From here, microplastics-contaminants and microplastics-pellets links were the most predominant. The results indicated that some of the primary harm caused by plastic litter is the dispersion of invasive species in addition to the leachates of the hazardous contaminants associated with plastic litter, such as persistent organic pollutants and phthalates. Finally, in Figure 3C, a total of 11 search terms were used which resulted in 309 studies and a total of 353 observations. The network graph highlights the link and observed effects on human health and economy, where fishing and tourism are more closely linked. In terms of fishing, marine litter can become entangled in gear and vessels, causing significant economic losses. The accumulation of marine litter and debris contributes to the degradation of pristine environments and landscapes, leading to loss of tourism revenue and an aesthetically unpleasant experience [23].

Conclusions

The results of the network analysis underline the primary lines of research on the impacts and effects of marine litter in coastal areas. Marine litter, primarily plastic pollution, in coastal marine ecosystems is a growing problem that is unlikely to decrease in the future without the application of stricter transboundary policies in addition to other management approaches such as extended producer responsibility schemes. Many of the primary harm discussed within the studies in the literature search include direct impacts which can cause environmental damage, disrupting the functioning and equilibrium of these areas and harmful effects on coastal biodiversity. Furthermore, many studies provide physical evidence, such as entanglement and ingestion of these items, which can have a variety of toxicological consequences, including irreparable harm and even death. Additionally, there are also several economic impacts that range from clean-up costs of marine litter removal to the destruction of fishing gear or endangerment by ships causing navigational harm. This has a variety of social consequences, including a negative public perception by reducing visual attractiveness, which may deter tourists, potentially creating indirect economic costs to local communities. In summary, this study highlights the global focus and predominant trends in current marine litter research.

Acknowledgements

Montserrat Compa is the recipient of a postdoctoral contract Juan de la Cierva-Formación (FJC2021-047606-I)) financed by MCIN/AEI/10.13039/501100011033 and the European Union NextGeneration EU/PRTR Recovery, Transformation and Resilience Plan. Antoni Sureda was granted by the Programme of Promotion of Biomedical Research and Health Sciences, Instituto de Salud Carlos III (CIBEROBN CB12/03/ 30038) and by the Spanish State Research Agency (Agencia Estatal de Investigación, AEI/10.13039/501100011033), the Spanish Ministry of Science and Innovation (Ministerio de Ciencia e Innovación, MCIN) and the European Union (NextGenerationEU/PRTR) through project PID2020–117686RB-C33.

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CITIZEN SCIENCE AND MACHINE LEARNING TO FORECAST *OSTREOPSIS* cf. *OVATA* BLOOMS IN THE ITALIAN SOUTHERN ADRIATIC SEA

Maddalena de Virgilio, Patrizia Borrello, Emanuela Spada, Pasquale Cataldo, Salvatore Cifarelli, Giuseppe Garofoli, Grazia Lamberti, Bernard Degryse, Ennio Ottaviani

Abstract: The toxic benthic dinoflagellate *Ostreopsis* cf. *ovat*a causes harmful algal blooms in Apulia region of Southern Italy.

In this study the volunteers of a citizens' observatory engaged with public research centres to apply a machine learning approach and develop a predictive modelling tool able to forecast *O. ovata* blooms.

We applied the Quantile Regression Forest to draw up two models named Model4Cities and Citizens'Model.

Model4Cities was trained with data of cell abundance detected by the Regional Agency of Environmental Protection of Apulia from 2010 to 2022 in the cities of Bisceglie, Molfetta, Giovinazzo and Bari where the microalgae proliferates at high rates.

Citizen'sModel was trained with data of cell abundance detected by citizens at two sites within the coastline of Molfetta from 2016 to 2022.

Both models show a good capacity to forecast *O. ovata* concentrations as function of meteorological open data with 81 % and 89 % of prediction accuracy.

Keywords: *Ostreopsis ovata*, forecast, citizen science, machine learning, Apulia Region

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Maddalena de Virgilio, Patrizia Borrello, Emanuela Spada, Pasquale Cataldo, Salvatore Cifarelli, Giuseppe Garofoli, Grazia Lamberti, Bernard Degryse, Ennio Ottaviani, *Citizen science and machine learning forecasting* Ostreopsis cf ovata *blooms*, pp. 881-891, DOI: 10.36253/979-12-215-0556-6.76

Introduction

Harmful Algal Blooms (HABs) are detrimental to humans, marine organisms and the environment [1].

Ostreopsis cf. *ovata* Fukoyo, 1981 belonging to the genus Ostreopsis Schmidt (Schimdit 1902) is one of the most common microalgae that produces palytoxin-like toxins (ova-toxin) [2, 3].

Ova-toxin represents a threat for human health via entry into the food chain, inhalation or direct contact [4,5,6].

Since the 1990s, *O. ovata*-generated HABs have been reported in the Mediterranean Sea particularly in Spain, France and Italy, sometime affecting more than 200 individuals [7,8,9,10].

O. ovata has been detected all over the Italian coast [3, 4, 11, 12].

Since summer 2007, in Apulia region of Southern Italy, the Regional Agency of Environmental Protection (ARPA-Puglia) performs a regular monitoring of the microalgae from June to September, included in the national surveillance monitoring (L 979/82, DM 30/3/2010, DM 19/4/2018). The aim of this monitoring is to provide alarms through public information in order to prevent the intoxication of beach users (DM 19/4/2018).

The cause of *O. ovata* blooms are not completely understood and the relationship with eutrophication and climate change has been hypothesised [13,14].

Pollutants may also serve as a "Go" signal favouring the growth of one planktonic species over the others [15, 16, 17].

Noteworthy, stretches of the coast impacted by intense anthropic exploitation are in general characterized by high proliferation rate of the benthic microalgae. As a consequence, human standings at the urban beaches are more exposed to the risk of intoxication [18].

However, as shown by separate studies, meteo-marine parameters play a pivotal role in permitting *Ostreopsis* proliferation.

A preliminary descriptive model of *O. ovata* blooms events in the Ligurian sea highlights a relevant role of seawater temperature and hydrodynamics [19].

In a machine learning based approach, data of *O. ovata* concentration and data provided by weather forecasting model operated by ARPA-Liguria were used to develop a predictive tool to predict HABs in this region of Nothern-Eastern Italy [20].

More recently, the statistical correlation between weather data freely available in open access databases (iLMeteo, seatmperature.info) and *O. ovata* concentrations detected in Molfetta allowed the identification of dew point as a new parameter that can be used to forecast blooms of the microalgae [21].

In this study the approaches citizen science and machine learning were combined to predict *O. ovata* abundances.

To this purpose the ensamble machine learning method Quantile Regression Forest (QRF) was applied to built two distinct models named Model4Cities and Citizens'Model [22].

Both models were trained to predict *O. ovata* cell densities in seawater as function of three meteorological parameters such as air temperature, seawater temperature and dewpoint deposited in iLMeteo and seatemperature.info open access archives.

Model4Cities was trained with data of *O. ovata* concentrations disclosed on the institutional website of ARPA-Puglia from summer 2010 to summer 2022 in 4 cities of Apulia where the microalgae proliferates at high rates (i.e. Bisce glie, Molfetta, Giovinazzo and Bari).

Citizens'Model was trained with data of *O. ovata* concentrations detected by citizens from summer 2016 to summer 2022 at two public beaches in Molfetta (i.e. Prima Cala and Gavetone).

Both models show a good capacity to forecast *O. ovata* concentrations and the related threshold exceedance probability as function of meteorological and marine open data with 81 % and 89 % prediction accuracy respectively, and are the base of developing an early-warning system for bloom events.

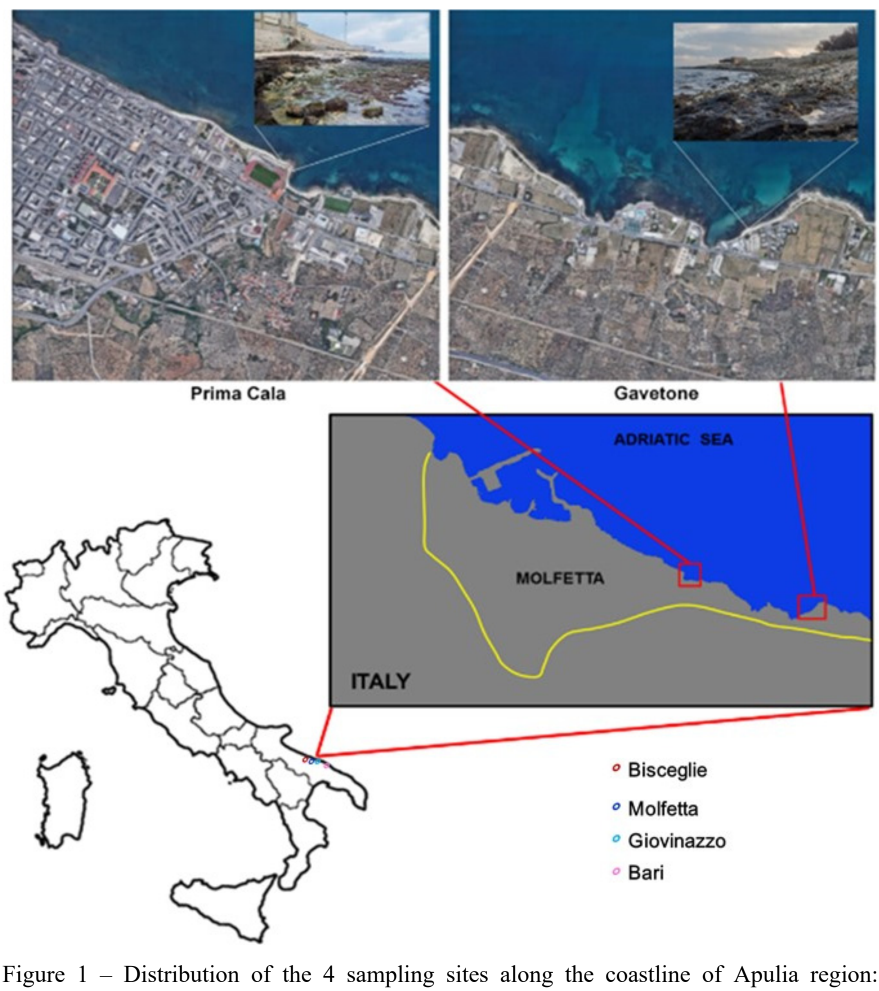

Figure 1 – Distribution of the 4 sampling sites along the coastline of Apulia region: Bisceglie, Molfetta, Giovinazzo, Bari, Molfetta-Prima Cala, Molfetta-Gavetone.

Materials and Methods

Study site

Since summer 2007, ARPA-Puglia carries out a survey along the coast of Apulia region from June to September, sampling seawater every two weeks.

In this study we have analysed the data of *O. ovata* abundance detected by ARPA-Puglia in the cities of Bisceglie (41°14’26,016” N;16°31’ 35,4” E), Molfetta (41°12’0,576” N; 16°36’59,076”E), Giovinazzo (41°10’25,32”N; 16°42’47,16”E) and Bari (41°6’29,16N; 16°56’15”E) from summer 2010 to summer 2022 (Figure 1). These 4 cities are located along a coastal stretch permanently subjected to the impact of large urban centres including the metropolitan city of Bari which itself accounts for 316 015 inhabitants and 2692 inhabitants km^{-2}.

In Molfetta, in a previous study, two sampling stations where chosen, namely Prima Cala (41◦11’5 N;16◦36’54“E) and Gavetone (41◦11’37N;16◦38’11”E) that are two public beaches crowded in summertime and separated from each other by a distance of 5 km. Prima Cala is the sampling station closer to the urban centre than Gavetone [21]. Seawater sampling in Molfetta was performed by citizens on a weekly basis.

Citizen science observatory/community-based environmental monitoring

Osservatorio del Mare a Molfetta (OMM, observatory of the Sea in Molfetta) is a community of volunteers promoting through the participative methodology of citizen science: i) the protection of coastal and marine ecosystem at urban level; ìi) the public’s rights to access to environmental information in order to empower citizens to make key decisions relating to environmental issues. In addition, OMM provides incentives to scientists to engage with citizens to establish the absence or presence of a cause-and-effect association between marine biodiversity loss and habitual pollution/consumption practices [21,23].

In this study, using their own devices, trained OMM-volunteers collected values of meteorological parameters and *O. ovata* concentrations from open access databases (www.arpapuglia.it; www.ilmeteo.it; www.seawatertemperature.info).

Meteorological parameters and statistical analysis

We have compared and statistically correlated the concentration of *O. ovata* bottom sampled by ARPA-Puglia from summer 2010 to summer 2022 with the mean of 7 meteorological parameters measurements during a period of 15 days in the past respecting to the date of seawater sampling at the cities of Bisceglie, Molfetta, Giovinazzo and Bari. The statistical correlation between the same weather parameters and the values of *O. ovata* density previously detected by citizens in two sampling station in Molfetta, i.e. Prima Cala and Gavetone, from July 2016 to December 2020 is described in de Virgilio et al. 2021[21]. The weather parameters that have been used herein were: average air temperature, seawater temperature, relative humidity (RH, proportion of humidity present in the air expressed in percent), air pressure (also known as atmospheric pressure or barometric pressure is the force exerted by the weight of the air per unit of area of the surface of Earth), dew point (at constant air pressure, it is the temperature at which air become saturated with water vapour, i.e. RH = 100%), maximal wind (or wind flow speed is the maximal speed of the wind), average wind (the mean of speed of the wind) and sea water temperature.

Statistical analysis was performed with the GraphPad Prism software using an ANOVA model followed by Tukey's post-test. Values $p < 0.05$ were considered significant, and $p < 0.01$ highly significant. Correlation between two variables was calculated using the Spearman's rank correlation coefficient.

Construction of the predictive model

In this study we applied the Quantile Regression Forest (QRF), an ensemble machine learning method, to build two predictive models of *O. ovata* concentration in sea water, using MATLAB as programming framework [22].

We selected the most important environmental predictors deduced from the statistical correlation (i.e. sea water temperature, average air temperature and dew point) and included into the model the values collected up to 15-days before the date of sampling. In this way, we aimed to capture the temporal evolution of the environmental variables with expected influence on concentration dynamics.

After a rank correlation analysis, we selected three time lags (2, 5 and 9 days) in order to cover the observed time span in days with a small number of values. Correlation between concentration and environmental variables peaked at 9 days in the past.

Doing so, the final vector used to define the regression model included 11 predictors:

- station ID (categorical)
- day of the year (numeric with range 1-365),
- 3 values for sea water temperatures corresponding to the 2nd, 5th and 9th day before test date;
- 3 values for average air temperatures corresponding to the 2nd, 5th and 9th day before test date;
- 3 values for dew point temperatures corresponding to the 2nd, 5th and 9th day before test date.

All features were encoded as continuous variables, except for station ID that was treated as a categorical variable with a number of unordered possible values corresponding to the different sites used in the training. We considered the station ID as a predictor since physical or geographical characteristics of the site may cause differences in the behaviour of *O. ovata* detected in bottom sampled sea water. The response variable was processed by the base-10 logarithm in order to deal with the large variation in concentration dynamics.

A total of 468 and 216 entries were present for the whole dataset of Model4Cities and Citizens' Model, respectively. The candidate blooms were defined with a threshold of 100 000 cell/L on *O. ovata* concentration in bottom sampled sea water.

Results were cross-validated using the out-of-bag (OOB) approach, as a common practice with tree-based models. In this way, a global assessment of the predictive capability of the model was generated. In a second step we also checked the temporal effectiveness of the method by splitting the dataset by year and using data of 2021 and 2022 in Model 4cities and data of 2020 and 2022 in Citizens' Model as an independent test data set.

Accuracy has been evaluated using MAE error metrics for the log-concentration.

Results

Correlations with meteorological parameters

We have previously demonstrated that at two distinct site along the coast of Molfetta, namely Prima Cala and Gavetone, the values of three specific weather parameters such as seawater temperature, dew point and, at a latter extent, air temperature exhibit a strong positive correlation with *O.* cf. *ovata* concentrations detected by volunteers [21].

In a like manner, as shown in table 1, calculation of Spearman's coefficient showed that the proliferation of the microalgae in the cities of Bisceglie, Molfetta, Giovinazzo and Bari detected by ARPA-Puglia from summer 2010 to summer 2022 positively correlates better with seawater temperature (ρ=0,52 at Bisceglie, ρ=0,55 at Molfetta, ρ=0,48 at Giovinazzo, ρ=0,59 at Bari) and dew point (ρ= 0,47 at Bisceglie, ρ= 0,53 at Molfetta, ρ= 0,48 at Giovinazzo, ρ= 0,52 at Bari) than air temperature (ρ= 0,24 at Bisceglie, ρ=0,35 at Molfetta, ρ= 0,4 at Giovinazzo, ρ= 0,37 at Bari).

Correlation coefficient very close to zero (and not significant) demonstrate that there is no relationship between high concentrations of *O. ovata* and the other weather parameters such as relative humidity, air pressure, average and maximal wind speed at the 4 sites considered in this study (Table 1).

Table 1 – Correlation between concentrations of *O. ovata* and weather parameters. Values of Spearman's correlation coefficient (ρ) are shown. Statistical significance is also indicated. p<0,05 is considered significant and p<0,001 highly significant.

Weather parameters	**Bisceglie**	**Molfetta**	**Giovinazzo**	**Bari**
Air temperature °C	0,24 p=0,0162	0,35 p=0,0007	0,4 p<0,0001	0,37 p<0,0001
Seawater temperature °C	0,52 p<0,0001	0, 55 p<0,0001	0,49; p<0,0001	0,59; p<0,0001
Dew point °C	0,47; p<0,0001	0,53 p<0,0001	0,48 p<0,0001	0,52 p<0,0001
Relative humidity (%)	0,1 p>0,05	0,06 p>0,05	-0,04 p>0,05	0 p>0,05
Air pressure (mb)	-0,03 p>0,05	-0,07 p>0,05	-0,02 p>0,05	-0,08 p>0,05
Wind average (km/h)	0,01 p>0,05	0,11 p>0,05	0,13 p>0,05	0,11 p>0,05
Wind maximal (km/h)	0,07 p>0,05	0,04 p>0,05	0,09 p>0,05	0,06 p>0,05

True and false positive rate

Data of *O. ovata* concentration collected from 2010 to 2022 by Arpa-Puglia were used to train Model4Cities where a total of 468 entries were present in the whole dataset including 144 candidate blooms throughout Bisceglie, Molfetta, Giovinazzo and Bari.

Data collected by citizens at Molfetta from 2016 to 2022 were used to train Citizen'sModel where a total of 216 entries were present in the whole data set with 81 candidate blooms throughout Prima Cala and Gavetone.

In both models, the probability at which an in situ *O. ovata* concentration above 100 000 cells/L in bottom sampled water was correctly predicted ("True bloom condition", i.e. True Positive Rate, TPR) was computed for the 50th quantile of the prediction in OOB mode. On the other way round, the probability of wrongly predicted bloom event when detected concentrations were below the specific threshold of 100 000 cells/L ("False bloom" conditions, i.e. False Positive Rate, FPR) was computed. Results were then plotted in Receiving Operating Characterisic (ROC) curves as TPR versus FPR for both models.

As shown in Figure 2A, the values of the Area Under Curve (AUC= 0,719; 0,933; 0,868; 0,902; 0,854 at Bisceglie, Molfetta, Giovinazzo, Bari and Mean, respectively) indicate a good capacity of Model4Cities to discriminate between positive and negative classes. In a similar trend, as shown in Figure 2B, the AUC values of Citizen'Model ROC curves (AUC=0,918; 0,957; 0,938 at Prima Cala, Gavetone and Mean, respectively) indicate that this model is endowed of an even better class separation capacity than Model4Cities.

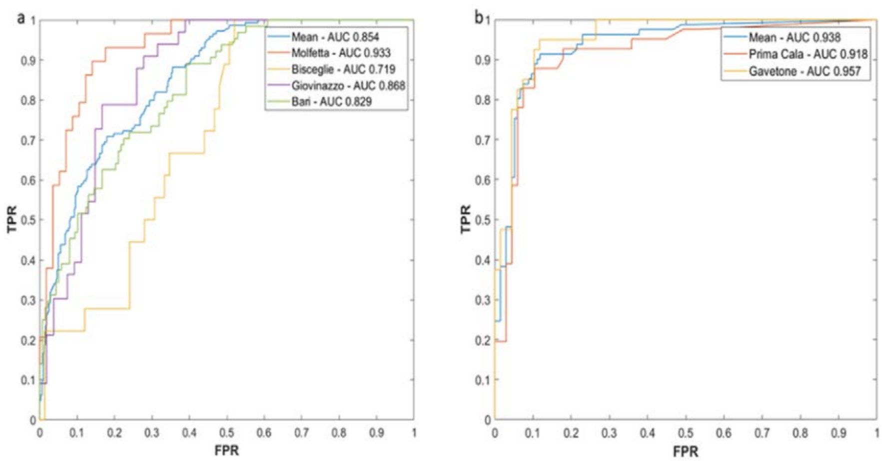

Figure 2 – ROC curves and AUC values for Model4Cities (a) and Citizen's Model (b). AUC > 0,5 indicates an acceptable class separation capacity, AUC=1 indicates optimal class separation capacity.

Confusion matrices were computed to provide a quantitative measurement of the accuracy and the errors made by the entire training datasets of both QRFs, comparing the predictions values with the actual measurements of *O. ovata* abundance detected by Arpa Puglia in Model4Cities or by citizens in Citizens'Model. These tests evidenced a good level of performance of both models with an accuracy of 81 % in Model4Cities (81 % for Bisceglie, 88 % for Molfetta, 80 % for Giovinazzo, 77 % for Bari) and an accuracy of 89 % in Citizens'Model (0,88 % at Prima Cala, 0,9 % at Gavetone).

Model Validation

Model4Cities validation was performed by generating predictions of *O. ovata* concentrations in bottom sampled water as function of the value of weather parameters occurring in summers 2022 and 2023 (77 samples) with a QRF trained with data spanning from summer 2010 to summer 2021 (431 samples) in Bisceglie Molfetta, Giovinazzo and Bari (mean AUC value=0,72). The values of predicted *O. ovata* concentrations were then compared with the actual cell concentrations detected by ARPA-Puglia and a confusion matrix of *O. ovata* concentrations threshold exceedance prediction was computed. With this data set, the accuracy of prediction of Model4Cities for summer 2022 and 2023 was 0,79 % throughout Bisceglie, Molfetta, Giovinazzo and Bari.

In a similar manner, the accuracy of predictions produced by Citizen'sModel in Molfetta at Prima Cala and Gavetone was validated. In this case, data corresponding to summers 2020 and 2022 (72 samples) were tested with a QRF trained from summer 2016 to summer 2019 (144 samples, mean AUC value=0,87). The values of predicted *O. ovata* concentrations were then compared with the actual cell densities detected by citizens in Molfetta in summers 2020 and 2022. The confusion matrix computed on this dataset indicates an accuracy of predictions for summers 2020 and 2022 of 81 % throughout Prima Cala and Gavetone.

Validation results were quite similar to those obtained with OOB procedure; therefore we are confident about the good generalization ability of the two models.

Discussion

Herein, we report the results of a collaboration established between volunteers of a citizens' observatory and public research centres with the aim of developing a forecasting system of *O. ovata* blooms in 4 cities of Apulia region of Southern Italy where the toxic microalgae proliferates at high rates affecting citizens standing on the coast.

Although it is well known that *O. ovata* represents a certain harm to human health and marine fauna, the dynamics of its blooms are still poorly understood [24].

Noteworthy, Pfannkuchen and colleagues have demonstrated that *Ostreopsis* blooms might remain undetected within conventional monitoring programs with high potential to affect human health [25]. Therefore, the development of an efficient predictive model to forecast *O. ovata* HABs is needed to reduce their impact on citizens' health.

In Apulia, since summer 2007, ARPA-Puglia performs a regular monitoring of the proliferation of the dinoflagellate in bottom and column sampled seawater every two weeks from June to September [26], included in the national surveillance monitoring (L 979/82, DM 30/3/2010, DM 19/4/2018).

Concomitantly, trained volunteers of a citizens' observatory monitored the microalgae from summer 2016 to summer 2022 at two different sites along the coast of Molfetta sampling seawater on a weekly basis [21].

In this study, we applied a machine learning approach to draw up two predictive models of *O. ovata* cell densities.

Herein, we show that a small set of meteorological parameters, such as air temperature, seawater temperature and dew point are sufficient to predict *Ostreopsis* HABs in the coastline stretch of Apulia including the cities of Bisceglie Molfetta, Giovinazzo and Bari.

In fact, both QRF exhibited a good level of performance as shown by the values of accuracy of predictions which were 81% and 89% for Model4Cities and Citizens'Model, respectively.

In both QRFs the response variable was the ten logarithm of *Ostreopis* cells concentration in bottom sampled seawater.

In the monitoring plan of ARPA Puglia, 30,000 cells/L is the threshold of *O. ovat*a concentration in the water column to disclose to the public warning about the onset of risks to human health (http://www.arpa.puglia.it, ISTISAN 14/9). Yet, we chose to consider values of cell concentration detected in bottom sampled water since they are less influenced by hydrodynamism in respect to values of cell density occurring in column water. Therefore, the most appropriate response variable would be the value of cell concentration in bottom sampled seawater [19].

In fact, *O. ovata* is a benthic species and its occurrence in the water column is due to the detachment from the bottom substrate and consequent resuspension in the water column as a result of water turbulence and/or of exceeding cells density on the bottom substrate [4, 19].

In addition, there is a tight coupling between the magnitude of *O. ovata* density in the water column and bottom sampled seawater: the higher is the concentration on the substrate, the higher is the abundance in the water column.

Predicted concentrations higher than the threshold value of 100 000 cells/L were considered as bloom events. Indeed this threshold value, chosen on the base of personal experience and previous observation [26], provided a high level of replicability in the prediction of blooms and increased the statistical inference of the two models.

Conclusion

We have performed a study on *O. ovata* proliferation dynamics using 10-years environmental data deposited in open access archives.

O. ovata blooms may remain undetected by conventional monitoring programs.

A small set of weather parameters such as seawater temperature, air temperature and dew point of previous days are sufficient to predict *O. ovata* blooms with good accuracy.

In this study, advances in knowledge have been achieved to improve the forecasting of *O. ovata* blooms in 4 cities of Apulia region of Southern Italy.

Model4Cities and Citizens'Model represent a cost-effective and reliable tool to forecast *O. ovata* concentrations and pave the way to the development of an early-warning system of bloom events.

Since both models are based on weather forecasts stored in open access archives, they can be easily scaled up at national and international level in all the areas affected by *O. ovata* HABs.

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THE ITALIAN COAST GUARD SURVEILLANCE AND SPECIFIC ENVIRONMENTAL ACTIVITIES. RESULTS OF THE NATIONAL CAMPAIGN

Federica Galeano, Clarissa Legari, Luca Patrizio, Angelo Villapiano, Tiziana Sinesi, Maura Pisconti

Abstract: Over the years, specific environmental maritime police campaigns have been thoroughly planned and carried out through the use of ITCG specialized units aiming at protecting the marine environment, in order to discover, analyze and repress environmental-harming activities. In 2023 the Environmental National Coordination Center planned a national campaign to prevent marine pollution and deployed also the Italian Coast Guard Environmental Analysis Laboratory. This operation was called «Clean Waters» and took place from 27th December 2022 to 30th April 2023: it involved all local Coast Guard offices and mainly focused on sites which could generate wastewater discharges. Hundreds of checks were carried out on specific targets and 55 wastewater samples were sent to the laboratory for subsequent analysis. Samples of waste water were analyzed, in order to ascertain any exceeding limits imposed by Italian law and to counteract potential pollution of the Italian seas. On the samples received we performed approximately 2000 chemical-physical, chemical and microbiological analyses; 12 samples resulted "non-compliant" due to 20 exceedings limits set by the Legislative Decree 152/2006.

Keywords: Measurement Methods and Instruments

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Federica Galeano, Clarissa Legari, Luca Patrizio, Angelo Villapiano, Tiziana Sinesi, Maura Pisconti, *The Italian Coast Guard surveillance and specific environmental activities. Results of the national campaign*, pp. 892-900, DOI: 10.36253/979-12-215-0556-6.77

Introduction

Over the years, specific environmental maritime police campaigns and complex operational activities have been thoroughly planned and carried out through the use of ITCG specialized units aiming at protecting the marine environment and the safeguard of the coasts and the biological resources, in order to discover, analyse and repress environmental-harming activities [2] [4].

In 2023 the Environmental National Coordination Centre planned a national campaign to prevent marine pollution and also deployed the Italian Coast Guard Environmental Analysis Laboratory. This campaign was called «Clean Waters» and took place from 27th December 2022 to 30th April 2023: it involved all local Coast Guard offices and mainly focused on sites which could generate waste water discharges likely to pollute the marine environmental matrices.

The operation aimed at protecting the marine and coastal environment through targeted control activities on the regularity of water discharges on the national territory, primarily through technical checks conducted by personnel qualified for sampling and personnel employed at the Coast Guard Laboratory for carrying out the analyses. The approach of decentralizing the sampling phase, already started and tested in the past, was therefore implemented [3].

The operation was divided into two distinct phases, one documentary and one operational. In the first phase - "documentary/ascertainment activity" - the territorial offices updated their waste censuses with the possible targets to be subjected to control, identifying, in their area of competence, the sites and production activities that could potentially produce waste water pollutants for the marine environment.

The types of discharges subjected to verification included: a) industrial waste discharges originating from shipyards − coastal depots − port facilities (for example, refineries, thermoelectric power plants, etc.) − car washes − laundries − swimming pools in sport-centers and hotel facilities or thermal spas − cheese factories − tanneries − paint factories and b) domestic waste water discharges coming from hotels, tourist villages and catering activities c) urban wastewater discharges − private and municipal purifier plants.

To identify the targets, open source applications available online and the technical reports relating to the remote sensing missions conducted by the Coast Guards aircraft were used, even prior to the CLEAN WATERS operation. Furthermore, each CG office involved acquired the documents related to environmental authorizations (for example discharge authorisation, single environmental authorization, integrated environmental authorization, agronomic use of sludge, use of waste water for fertigation, etc.) in an order to focus the control activity primarily on those establishments that hypothetically could lack them. Controls were also carried out on sites with all the authorizations, verifying their compliance with the provisions. Furthermore, important information was also acquired through the Chamber of Commerce's record, as well as by consulting the institutional pages of the relevant Authorities.

This first phase was carried out ensuring a confidential approach for the acquisition of documentation in order not to invalidate the subsequent operational phase.

In the second phase - "operational activity" - targeted checks and inspections regarding water discharges were carried out. Both the Marine Environmental Control Centres (MECC) for regional coordination and the Environmental Police Operational Units (EPOU) – present in all CG offices - were involved in carrying out the activities. The team was made up of at least one unit of CG personnel belonging to the EPOU, in possession of specific training and/or proven experience in environmental matters; and, where available, also at least one unit trained in "Surface Water and Marine Sediment Sampling Techniques"; both units were responsible for all activities among which inspections and sampling. To carry out the sampling, all personnel was trained through the documents available on-line - in particular the LAB_001 operational directive - the sampling techniques manual and the procedure to transport the samples, through a specialized company, to the CG Environmental Analysis Laboratory.

Joint activities have also been planned with other Police Forces operating locally and/or with the Authorities responsible for environmental control/monitoring (Provinces, Metropolitan Cities, ARPA), when the sites to inspect could be linked, due to their characteristics and typology, to individuals affiliated with criminal associations as well as to avoid compromising any ongoing investigations.

Regarding the use of the scientific units, each CG Office sent at least one sample to the Fiumicino Environmental Analysis Laboratory according to a shared calendar, developed in order to allow the correct management of the transport and acceptance of the samples for the subsequent execution of the analyses.

In this case, the operators sent a sample of waste water taken from the inputs into surface water or from the exit well of the selected purification plants.

The activities releasing huge quantities of urban or industrial waste water (for example companies specialized in dairy production) were subject of multiple inspections in the adjacent areas, even at night, with the aim of identifying any pipes installed illegally (so-called bypasses) to discharge the wastewater without preliminary passage through the pre-treatment systems or to reduce the flow rate so as to comply with the limits and requirements set out in the environmental authorisations.

Furthermore, observation, control and shadowing activities were organised aimed at having a complete picture of the situation external to these production facilities, in order to identify any suspicious movements (for example, companies that intend to deliver their liquid waste to unauthorized purifiers) and calibrate the number of operators to be used in the control phase according to the extension of the area to be inspected and the subjects operating there. To support the teams, the CCNA made tools available for immediate consultation such as updates to the environmental regulations and forms/checklists for conducting the inspection activity.

Materials and Methods

In order to assure the role of the Coast Guard as an operational instrument for the implementation of the functions regarding the protection of the marine and coastal environment, on behalf of the Ministry of Environment, a complex "Environmental Strategy" has been drawn up and approved, characterizing the activities of marine environmental police carried out by the ITCG staff. As part of the environmental protection, the operation " CLEAN WATERS ", planned and coordinated by the Plans and Operations Department of ITCG Headquarters, provided a coordinated and synergical use of the specialist units to discover, analyse and immediately repress illicit phenomena that may affect the environment.

In the national operational “CLEAN WATERS” an important role was played by the Environmental Analysis Laboratory of the ITCG "CF (CP) Natale DE GRAZIA" – LAB.GC.

The Environmental Analysis Laboratory consists of 2 Mobile Environmental Laboratories (LAM) and a traditional Laboratory (LAB) located at Fiumicino CG Office [1]. The Laboratory is run by qualified biologists and duly trained technicians able to perform both the sampling and analytical phase, using LAM and LAB instruments. The Laboratory, thanks to its specialized organization, can operate in dual use: ITCG employs the LAM asset to carry out sampling activities and on field analysis, and LAB asset to perform the full range of analysis by using more advanced equipment to analyse the water samples provided by the local CG Offices. In December 2021 an important milestone was reached: the accreditation of the Laboratory Environmental Analysis "CF (CP) Natale DE GRAZIA", which is added to the quality certification ISO 9001, issued by RINA in 2013. ACCREDIA, Single National Accreditation Body, has issued the certificate attesting the competence, independence and impartiality of the Laboratory in compliance with the requirements of the technical standard UNI EN ISO IEC 17025 strengthening even more the validity of the analytical results obtained in the laboratory and used in administrative and criminal proceedings.

Results

During the environmental operation, 7770 activities on land and 1425 missions were carried out using naval vessels for a total of 39512 hours of activity divided into 4 time slots covering 24 hours.

The two time slots (06pm/midnight and midnight/06am) were mainly used for investigative activities and to monitor those sites where crimes were more likely to occur.

The data, summarized in the table (figure 1), highlights that the focus of the activity was centred on the port areas and in particular on the purifiers, sites which, in most cases, discharge waste water directly into the sea.

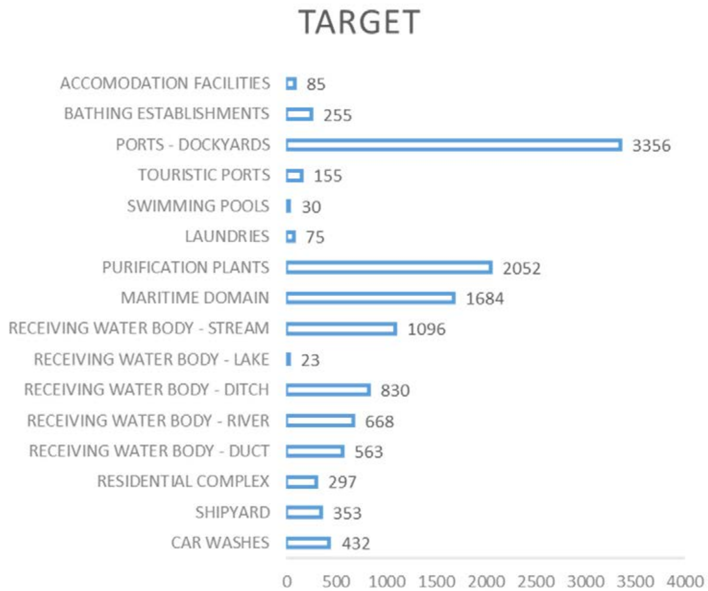

Figure 1 – Main target of the national operation "Clean waters".

The over 2000 checks were distributed across three different types of purification plants, urban, domestic and industrial wastewater, as shown in the following graph (figure 2):

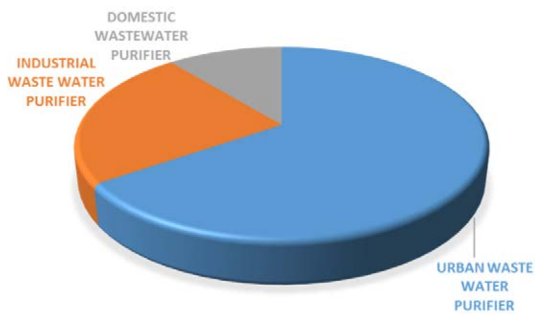

Figure 2 – Main type of purification plants checked.

This strategic choice was positively evaluated for the protection not only of surface water bodies and therefore of the delicate ecosystems of the marine-coastal environment, but also as a guarantee for the citizens due to the imminence of the summer season.

Overall, no. 17245 checks were conducted on water discharges, plus the other relevant activity carried out by local CG Offices, the outcome of which is reported:

- ✓ 9414 controls regarding the waste cycle;
- ✓ 11721 checks regarding the prevention/detection of pollution at sea.

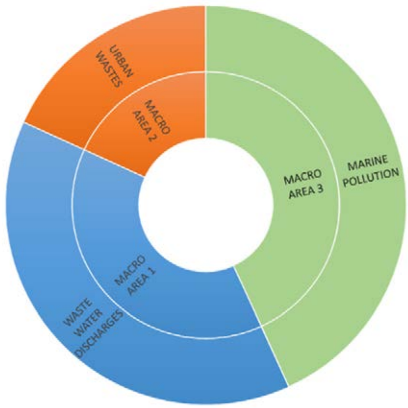

Figure 3 – Main type of control.

Overall, during the «CLEAN WATERS» operation, 38,380 detailed checks were carried out along the entire national coastal strip (approximately 7.500 km) distributed as per the cartography below (figure 4).

Figure 4 – Ascertains distribution.

Following the activity in which were carried out, the owners of the companies were reported to the Judicial Authority the pertaining structures were seized and the process envisaged by the Environmental Law for the extinction of the contested crimes through the release of a prescription technically certified by the local ARPA was started. While the complex operation made some critical issues come to light, it also contributed to curbing some of the most environmentally damaging behaviours.

Environmental controls regarding discharges led to the investigation and reporting of 271 offences:

- 171 administrative;
- 100 penal.

63 people and 37 legal entities were reported to the Judicial Authority.

The main administrative sanctions contested are related to the lack of authorization to discharge domestic waste, exceeding the emission limit values set in the tables of the Environmental Law (T.U.A.) and failure to comply with the requirements indicated in the authorization provision, as reported below (figure 5).

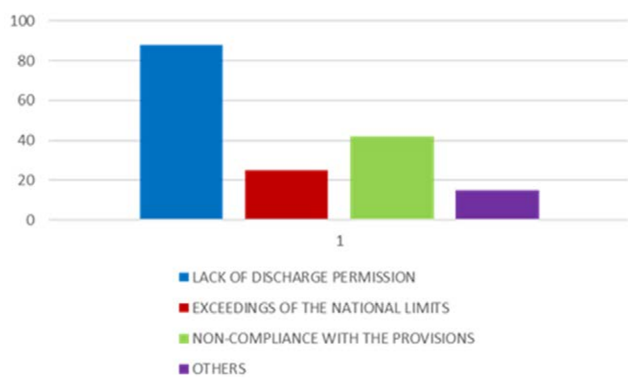

Figure 5 – Main penalties found.

The total amount of administrative sanctions issued varies between 485 000 € and 4 850 000 €. For this type of sanctions, as the legislator consider them particularly severe and harmful, no reduced payment is allowed. It is the responsibility of the competent authority (Region/Province/Metropolitan City/Municipality) to issue the injunction with the exact amount due.

The main crime reports sent to the competent Judicial Authority. concern the lack of authorization for the discharge of industrial wastewater and the discharges into the soil and subsoil in the absence of authorization or in non-compliance with the relevant instructions.

As part of the operation, the «CF (CP) Natale DE GRAZIA» Environmental Analysis Laboratory of the Coast Guard was deployed to continuously support the operational activities of the CG Offices which, according to the Action plan of the operation, carried out a series of samples - involving trained personnel - on previously identified waste water, with subsequent sending of the samples. The refrigerated and controlled transport of the samples, according to the methods and timing required by technical regulations, was carried out by a highly specialized company, contracted by the ITCG General Headquarters.

The constant support granted by the laboratory staff has contributed to achieve the objective of consolidating skills and increasing the staff's capacity in managing the sampling, conservation and transport procedures of samples which represent critical phases of the analytical process.

Between January and April 2023, 54 samples were received at the laboratory, consisting of "waste water" matrix, mostly taken from the sampling point at the exit of purification plants. The correct application of the standardized sampling procedures and the efficiency of the transport chain guaranteed the validity of all the samples received for carrying out the analyses by the Laboratory personnel (figure 6), according to the standards set by the T.U.A. and from the APAT CNR IRSA Manual Man 29/2003 «Analytical methods for water».

Figure 6 – Environmental Analysis Laboratory personnel

12 out of the 54 samples received, on which approximately 2000 chemical-physical, chemical and microbiological analyses were performed, were found non-compliant. The analytical results allowed the detection of n. 20 exceeding the tabular limits provided for in the third part of Legislative Decree no. 152/2006 and/or individual environmental authorizations, divided as follows:

- ✓ n. 13 relating to chemical parameters (total nitrogen, ammoniacal nitrogen, nitrous nitrogen – nitrites, total surfactants and chlorides);
- ✓ n. 7 relating to the microbiological parameter *Escherichia coli*.

The verification of exceeding the legal limits was included in formal reports issued by the laboratory, and subsequently notified to the violators by the competent CG Office.

Discussion and Conclusion

The over 2000 checks carried out as part of the national CLEAN WATERS operation led to the detection of numerous crimes, both administrative and penal, regarding waste and in particular water discharges. The focus of the activity was centred on a critical sector in Italy such as purification; infact the selected targets were mostly treatment plants located along the national coast which discharge waste water directly into the sea, therefore potentially more harmful to the marine and coastal environment.

The Coast Guard's activity, aimed at protecting delicate coastal ecosystems, contributed to the pursuit of the institutional objective assigned by the Ministry of the Environment and the results obtained confirmed the effectiveness of the strategic choice of the entire operation.

Furthermore, given the excellent results, a follow-up activity was also organized to strengthen the prevention and fight against marine pollution and increase surveillance in Marine Protected Areas as per the Agreement signed on 3rd November 2022 by the Minister of the Environment and Energy Security and the General Commandant of the Coast Guard.

The operational activity was carried out between 18th September 2023 and 10th November 2023, involving the Environmental Analysis Laboratory «C.F. (CP) Natale DE GRAZIA» employed in mobile (LAM) and traditional (LAB) operational set-up to carry out analyses on 19 samples of waste water matrix provided by the local CG Offices, in the most anthropized Marine Protected Areas.

The analyses carried out on these samples revealed some exceeding of the tabular limits indicated both in the Environmental Law (T.U.A.) and in the individual authorization documents; in particular, 12 non-conformities were found relating to the chemical parameters and 2 NC for the *E. coli* parameter, reported in the relevant test reports, used by the Commands to contest the offenses found.

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WAVE TRANSMISSION OF FIXED BOTTOM-DETACHED BREAKWATERS IN NUMERICAL WAVE FLUME

Zihan Liu, Andrea Esposito, Lorenzo Cappietti

Abstract: This work presents preliminary numerical simulation results on wave interaction with a fixed Bottom-Detached Breakwater (BDB). The purpose of developing fixed BDB is to provide a safe offshore zone for human activities, such as energy production and docking of large vessels, even in extreme weather. The transmission coefficient (k_t) is used to assess the protection performance of the BDB. A two-dimensional Numerical Wave Flume (NWF) was developed by using ANSYS Fluent, validated with existing data and then used for studying the interaction between extreme waves and the BDB. The role of BDB design parameters such as its width and draft, and wave height and wavelength on k_t was investigated. The reliability of the results of k_t was verified by previous experimental study. This study demonstrates the development of a reliable NWF for conducting parametric analysis of BDBs and is a kick-off study for further developing the numerical and experimental study of floating breakwaters.

Keywords: Wave-structure interaction; transmission coefficient; bottom-detached breakwater (BDB); numerical wave flume; computational fluid dynamics

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

1 Introduction

Very Large Floating Structure (VLFS) presents a potential solution for expanding operational space and efficiently use the maritime space, and it could address seawater level rising and land subsidence with a resilient approach [1]. Maritime concrete caissons are the primary components of breakwaters and harbours. The size of existing maritime concrete caissons could reach up to 67 m in length, 35 m in width, and 33 m in height as for the Genova's harbour breakwater (Italy), presently under building (July 2024).

Various studies have proposed methods for predicting the transmission coefficient (k_t) of breakwaters [2-4]. One of the most well-known formulas for predicting k_t, particularly for box-type breakwaters, was derived by Macagno [5-7] using linear wave theory. Ursell [8] developed a formula for predicting the k_t in deep-water regions, identifying relative draft (the ratio of draft to wavelength) as a crucial factor. Carr [6] conducted a foundational study on floating breakwaters in shallow water and derived the first formula for shallow-water conditions. Kolahdooza et al. [6] later improved Carr's formula which offered more accurate predictions of k_t in shallow waters. When compared with laboratory and prototype results, particularly for short waves or large drafts relative to mean sea level, the Macagno's formula predictions were qualitatively correct but generally inaccurate. Ruol et. al [5] proposed a modification factor for Macagno's formula to better predict the k_t of various π-type pontoon floating breakwaters. Ruol's empirical formula accounts for the motion effects of the structure, improving Macagno's formula for application to π-type breakwaters and it has been verified by researchers to predict the k_t of pontoon-type and π-type floating breakwaters [9]. However, it has been observed that in shallow and intermediate waves, Ruol's formula was less accurate than Carr's formula [6]. Paotonan et al. [10] introduced a new type of composite hanging breakwater, which is suspended from transverse and longitudinal beams supported by piles.

To date, most studies have focused on relatively small- and mid-sized breakwater located in intermediate and shallow waters, often within naturally protected marine areas and under mild wave conditions. The interaction between extreme waves and large-sized breakwater should be further explored. In this work, a fixed Bottom-Detached Breakwater (BDB) is considered an ideal precursor to floating breakwaters, with its displacement strictly controlled by mooring and anchor systems. A Computational Fluid Dynamics (CFD) tool, ANSYS Fluent, was used to develop and calibrate a two-dimensional (2D) Numerical Wave Flume (NWF) for generating various waves with high accuracy. The study investigates the influence of wave conditions and BDB dimensions on k_t, including the performance of BDBs with large draft (D_{FB}) and width (W_{FB}) under extreme wave conditions in offshore waters. This article provides a research basis for the experimental studies of fixed BDB and floating breakwater, presently under conduction at LABIMA the Laboratory of Maritime Engineering at the University of Florence (www.labima.unifi.it).

2 Materials and Methods

2.1 Numerical wave flume and fixed bottom-detached breakwater (BDB)

As shown in shown in Figure 1, a 20 m long NWF is divided into several regions, including air, water, refined and wave attenuating regions. The air and water regions are separated by free water surface. The height of NWF is 2 m while the water depth is 1.0 m. To capture the behaviour of free surface wave motion, the refined region is ±0.1 m around the water surface (i.e. about ± the maximum generated wave height). The wave attenuating region, a 3 m long numerical beach, is located at the end of NWF for absorbing incident waves thus avoiding the wave reflection caused by end of the NWF. Two Wave Gauges (WGs), WG-a and WG-b, are respectively installed 1.4 m and 7.0 m far from wave generation section.

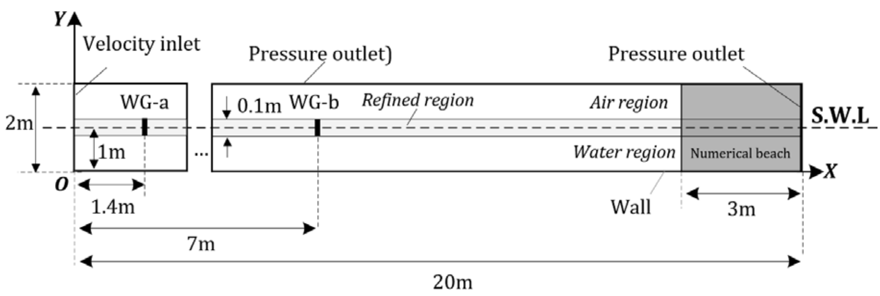


Figure 1 – Sketch of the 20 m long NWT.

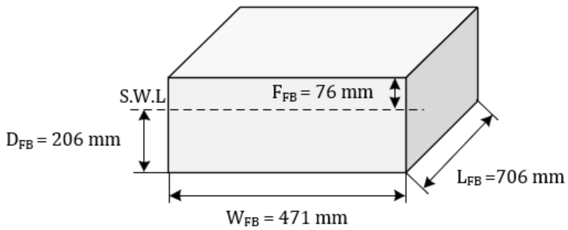


Figure 2 – Sketch of fixed BDB at a representative model scale 1:170.

In order to quantify the quality of wave generation in the NWF, the relative error (RE) and the wave decay coefficient (γ) as defined in Eq. 1 and Eq. 2 are used.

$$\mathrm{RE} = \frac{\mathrm{H_0 - Hb}}{\mathrm{H_0}} \times 100\% \qquad \text{Eq. 1}$$

$$\gamma = \frac{\mathrm{H_a - H_b}}{\mathrm{H_a}} \times 100\% \qquad \text{Eq. 2}$$

where, H_a and H_b are the wave height measured by WG-a and WG-b, respectively; RE represents the relative error between the target wave height (H_0) and the practical wave height (H_b); γ is the decay of wave height between the wave height at the benchmark (H_a) and the practical wave height (H_b).

In offshore extreme weather, the designed BDB must provide a workable situation for the safe berthing of vessels. k_t is an important indicator, which is the ratio of transmitted wave height (H_t) over incident wave height (H_i) to evaluate the protection performance of BDB. Based on Macagno's formula [5,6] for selecting the necessary draft and width to limit k_t to acceptable values and considering the requirements for acceptable overtopping [11] for selecting the BDB's freeboard the designed dimensions of the BDB's model are shown in Figure 2 at the representative model scale (λ) 1:170.

2.2 Methods

ANSYS Fluent is a widely used CFD package, based on Finite Volume Method (FVM), to solve the complex phenomenon in wave-structure interaction, which can be described by continuity (Eq. 3) and N-S equations (Eq. 4) for incompressible and homogeneous fluids.

$$\frac{\partial u_i}{\partial x_i} = 0 \qquad \text{Eq. 3}$$

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + g_i + \frac{1}{\rho}\frac{\partial \tau_{ij}}{\partial x_j} \qquad \text{Eq. 4}$$

where i=1,2 and j=1,2 for two-dimension flow; u_i: velocity components; p: pressure; g_i: gravitational acceleration components (just along the vertical axes); τ_{ij}: stress tensor. Those equations are based on time-averaging that introduces Reynolds stress terms associated with mean flow variables so that a turbulence closure model is needed. In this work, 2D numerical simulation is adopted.

Wave damping effects taking place during wave propagation along the NWF should be limited to realistic value. Based on the applicable range of wave theories, Stokes 2nd order wave was adopted to provide the reference for verifying the accuracy of wave generation [12]. The BDB is designed in offshore extreme weather for creating a safe zone with limited k_t up to extreme wave condition of 100-year return period. As reference value for the 100-year return period wave condition for the Mediterranean Sea, incident wave height (H_i) of 0.043 m, wave period (T_p) of 0.94 s, wavelength (L_w) of 1.39 m in a water depth (d_w) of 1.0 m, are selected for calibrating the NWF (the values are scale 1:170). Moreover, the influence of wave conditions and BDB design parameters were numerically studied even under the wider ranges comprising H_i=0.01~0.07 m, L_w=0.9~3.1 m, D_{FB}=19÷206 mm and W_{FB}=25÷550 mm.

In the NWF, the so-called Velocity Inlet is used for wave inlet boundary; Pressure Outlet is adopted for wave outlet and top boundaries; Wall type is adopted for seabed and BDB boundaries. The sub-models (Open Channel Wave BC and

Open Channel Flow [13]) in VOF are activated for generating wave at inlet boundary and attenuating wave in numerical beach. To cope with the spatial discretization, Least Square Cell Based was used for gradient. Modified Body Force Weighted was adopted for pressure. The air and water phases were incompressible and Modified High Resolution Interface Capturing method was used for defining the free surface. Spatial discretization is Second Order Upwind.

3 Results and Discussion

3.1 Calibration of NWF

The influence of different numerical settings (time step, turbulent model, velocity-pressure coupling method and transient formulation) on the accuracy of wave generation are studied. The free surface wave motions measured by WG-b by adopting various numerical settings are shown in Figure 3. In this work, the time step is 0.002 s; turbulent model is k-e RNG; Velocity-Pressure coupling method is PISO; Transient formulation is Second Order Implicit.

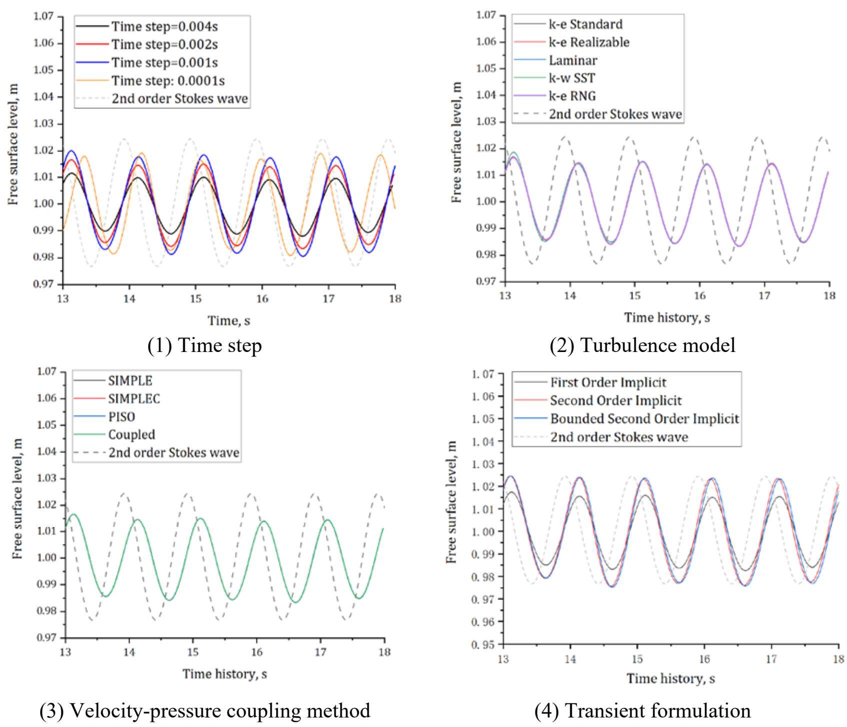


Figure 3 – The influence of different numerical settings on the free surface wave motion recorded by the WG-b (i,e, 7 m far from the wave generation section).

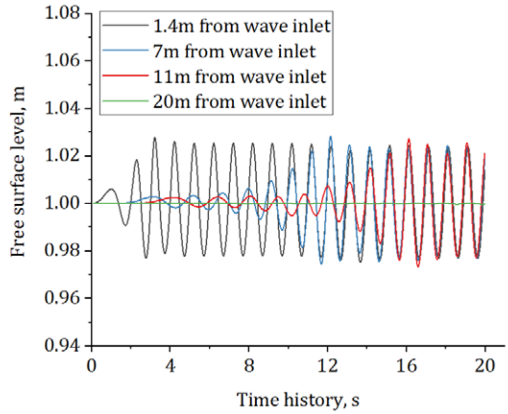
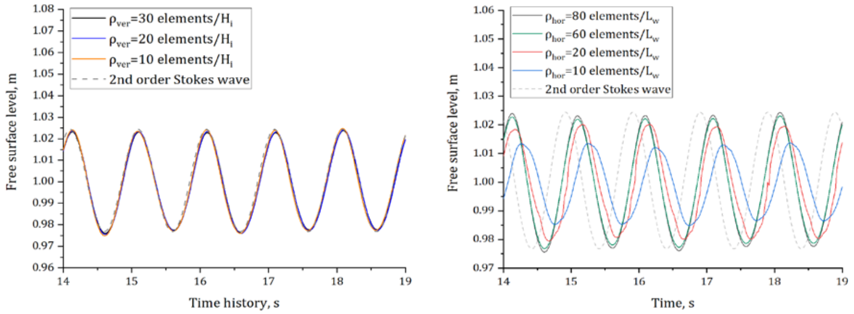


Figure 4 – Time histories of the free surface levels at different NWF sections (1.4 m, 7 m, 11 m and 20 m far from wave inlet).

Considering that when the transmitted wave reaches the end of NWF it is reflected by the wave outlet boundary, a Numerical Beach (wave attenuating region) was activated for attenuating the wave at the end of NWF thus limiting the reflection to tolerable values. The time histories of the free surface levels at different positions (1.4 m, 7 m, 11 m and 20 m far from wave inlet) along the 20 m NWF are shown in Figure 4. It shown that the free surface wave motion at the and of the NWF, i.e. 20 m far from the wave inlet, is much weaker compared with those measured in other positions, which indicates that the numerical beach efficiently attenuates wave energy. After 13 s, the free surface wave motion measured by WG-b becomes fully developed and stable.

Loose mesh scheme induces numerical inaccuracy and instability, and the over refined mesh scheme does not lead to better results and requires more time cost. To select the best compromise in term accuracy of results and computation efforts a sensitivity analysis on mash size was conducted, by using the 100-year return period wave condition, Figure 5. ρ_{ver} is the mesh resolution in the vertical direction in the refined region near the free surface; ρ_{hor} is the mesh resolution along the horizontal direction in NWF. Based on the wave height measured by WG-a and WG-b, the RE and γ that characterize the developed NWF can be controlled within 2 %, when ρ_{hor}=80 elements/L_w and ρ_{ver}=15 elements/H_i. When the BDB in installed into the NWT, the mesh resolutions near its the vertical and horizontal walls are 200 elements/L_w and 62 elements/H_i, respectively.



(1) Influence of ρ_{ver} (2) Influence of ρ_{hor}

Figure 5 – Influence of the mesh resolutions on the free surface wav emotion measured at WG-b located 7 m far from the wave inlet.

3.2 Verification of numerical tool

The experimental tests carried out by Liang et al. [3] were used for validating the reliability of the developed NWF in simulating the transmitted wave in the following test conditions: W_{FB}=0.5 m, D_{FB}=0.16 m, W_{FB}/L_w=0.13-0.33, H_i=0.07 m and d_w=0.6 m. The distance between the fixed BDB and wave inlet was 7 m, and the k_t was tested 0.33 m behind it. The comparison between the results of k_t from the numerical simulation of this work and the experimental result from Liang et al. is shown in Figure 6. The numerical results of k_t well match previous experimental results.

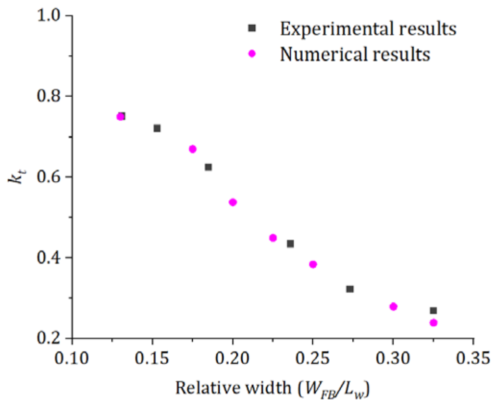
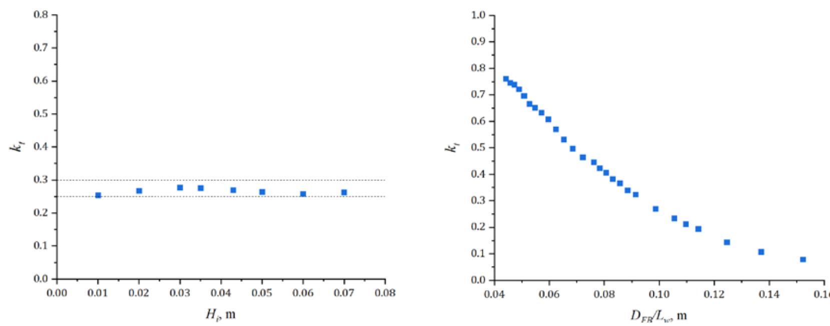


Figure 6 – Comparison between numerical results of k_t obtained via the NWT and experimental measurements from Liang et al. [3] (W_{FB}=0.5 m, D_{FB}=0.16 m, W_{FB}/L_w=0.13÷0.33, H_i=0.07 m and d_w=0.6 m)

3.3 Sensitivity analysis of k_t to wave conditions and BDB's design parameters

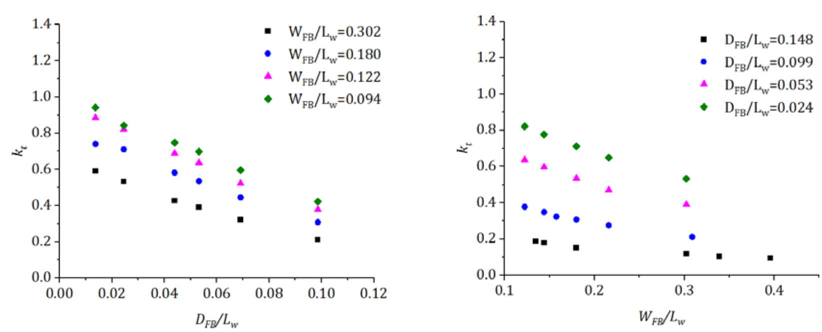
The influence of H_i and L_w on the k_t of fixed BDB are shown in Figure 7. With the increasing of H_i, the change of k_t is small, but with the increasing of D_{FB}/L_w (here obtained by decreasing L_w), the k_t strongly decreases. Those are because the wave energy mostly concentrates near the free surface and for the fixed wave period used in the tests with varying H_i it is almost blocked by BDB thus the change of H_i has little influence on k_t. On the contrary, with the decreasing of D_{FB}/L_w by increasing the wave period and so by increasing the wavelength more wave energy is driven by wave and passes beneath the BDB, which causes the increment of k_t [12].

Due to the extreme weather in offshore environment, the dimensions of BDB are very large, which leads to expensive investment cost of materials, and should be optimized for avoiding over engineering design. The influence of relative width (W_{FB}/L_w) and relative draft (D_{FB}/L_w) on the k_t of BDB under the selected 100-year return period wave condition are shown in Figure 8. With the increment of D_{FB}/L_w and W_{FB}/L_w the k_t decreases because larger D_{FB} values block a larger part of the wave energy and because larger W_{FB} values induce larger hydrodynamic damping.



(1) The influence of H_i on k_t. (2) The influence of D_{FB}/L_w on k_t.

Figure 7 – The influence of H_i and L_w on the k_t of deep-draft fixed BDB (H_i=0.01~0.07 m, L_w=0.9~3.1 m, D_{FB}=206 mm and W_{FB}=471 mm).



(1) The influence of D_{FB}/L_w on k_t for different W_{FB}/L_w (2) The influence of W_{FB}/L_w on k_t for different D_{FB}/L_w

Figure 8 – The influence of the BDB's design parameters on k_t under the 100-year return period wave condition (H_i=0.043 m, T_p=1.0 s, D_{FB}=19÷206 mm and W_{FB}=25÷550 mm).

4 Conclusion

A reliable NEW for studying the interaction between extreme waves and deep-draft fixed BDB was developed. The reliability of the developed NWF for measuring the k_t of BDB was verified throughout comparison with available experimental measurements conducted by other authors. The influence of wave conditions on the k_t of deep-draft fixed BDB was examined. The results indicate that H_i has a minimal impact on k_t, while D_{FB}/L_w significantly affects k_t. As D_{FB}/L_w decreases (L_w increases), k_t increases, as longer waves drive more energy propagating beneath the BDB bottom. As W_{FB}/L_w increases the k_t decreases because increased hydrodynamic damping caused by the larger W_{FB}.

This work serves as the seed study for the further development of the work on floating structures and mooring system.

Acknowledgements

This work is supported by the Tuscany Region (TR) administration, under the PEGASO initiative, that financed the PhD scholarship of Zihan Liu, and by AM3 Spinoff s.r.l. the spinoff company of the Florence University (AM3-UNIFI) that is co-financing Zihan Liu with an internship and it is partner of the Joint Laboratory A-MARE, www.amare.unifi.it. TR and AM3-UNIFI are gratefully acknowledged.

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MODELING THE HIGH-IMPACT LOW-PROBABILITY OIL SPILLS IN THE MEDITERRANEAN

Svitlana Liubartseva, Giovanni Coppini, Pierre Daniel, Megi Hoxhaj

Abstract: Despite considerable efforts to improve scientific understanding and risk management, governments and businesses remain insufficiently prepared to confront large oil spills considered to be the so called 'high-impact low-probability' disasters.
To alleviate this problem, we focus on the historical *HAVEN* oil spill (off the Port of Genoa, 1991) recognized not only as the largest shipwreck in the European waters, but also as one of the worst oil pollution cases in the Med.
We reconstruct this spill with the Lagrangian oil spill model MEDSLIK-II forced by the to-date high resolution meteo-oceanographic datasets.
Moreover, we run the *HAVEN* oil spill scenario stochastically sampling virtual spills randomly in space and time. The results are presented as the pollution hazard indices in probabilistic terms, which is supposed to be a representative indicator of future accidents. The highest indices are found in the Alboran Sea, Algerian and Liguro-Provençal subbasins, and in the center of the Ionian Sea. Conversely, the southern part of the Ionian, the areas east of Sardinia and west of Corsica, the Gulf of Lion, the northern Adriatic, and north-eastern Aegean Sea do not reveal high hazards.

Keywords: oil spill modeling, hazard mapping, Copernicus Marine Service

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Svitlana Liubartseva, Giovanni Coppini, Pierre Daniel, Megi Hoxhaj, *Modeling the high-impact-low-probability oil spills in the Mediterranean*, pp. 911-922, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.79

Introduction

Large oil spills can be considered the High Impact Low Probability (HILP) events that confront scientists and decision-makers with new challenges. In both environmental and economic terms, the costs of these spills are considerable. Marine biota can be seriously affected due to direct toxic effects and physical smothering. Loss of natural habitat or shelter might lead to elimination of vulnerable species. Fishery and mariculture resources can be severely damaged due to toxic effects on stock and disruption of business activities. In addition to the costs incurred in cleaning up oil spills, serious financial losses are experienced by economic sectors that rely on clean seawater and clean coastal areas: tourism, salt production, sea water desalination, and power plants.

Occurrence of large oil spills is fundamentally a matter of probability. The DeepWater Horizon (DWH) oil spill (the Gulf of Mexico, 2010) is a canonical example of such a 'high-impact low-probability' catastrophe. The extent of exposure has been extensively studied, and many researches confirmed its disastrous impact (e.g., [1, 2]). Moreover, some oil residues buried in beaches are found to persist for years to decades [3].

Actually, a common feature of such the extreme oil spills is that they rarely occur, and few data are available to statistically describe them [4]. Nevertheless, the probability of catastrophic oil spills can be assessed by the Extreme Value Theory (EVT). Applying EVT to the US outer continental shelf areas, it was concluded that a spill as large as the DWH spill will take 165 years to return. Notably, a 95 % confidence interval has found to be quite wide ranging from 41 to over 500 years [5].

Dealing with the Mediterranean, we focus on the historical VLCC *HAVEN* oil spill (off the Port of Genoa, 1991), which was recognized not only as the largest shipwreck in the European waters, but also as one of the worst oil pollution cases in the Mediterranean.

In this work, we present a model-based reconstruction of this spill movement using the freely available hindcast of the marine hydrodynamics provided by the Copernicus Marine Service and the wind speed by the European Centre for Medium-Range Weather Forecasts (ECMWF). Model results are validated with the available observational data.

Since any reliable statistics on past oil spills is not available for the Mediterranean [6], we could hardly estimate the return period for the *HAVEN* oil spill. We can only hypothesize that the corresponding confidence interval will be approximately as wide as the DWH interval. However, we can compute a conditional probability, assuming that a large oil spill, such as the *HAVEN* spill, will occur at a certain location in the Mediterranean in the future.

To this end, we launch stochastic oil spill simulations [7 - 9] to map oil pollution hazards in probabilistic terms. For the various areas of the world ocean, such kind of simulations were run many times from point-type and distributed sources (find some overviews in [10, 11]), but for the first time, we initiate them from non-uniformly distributed sources across the entire Mediterranean.

To model oil drift and transformation, we use the Lagrangian oil spill model MEDSLIK-II [12]. Initial distribution of oil spill sources is currently associated with large uncertainties. Recent satellite-derived maps of chronic oiling [13] are employed to seed virtual spills in the stochastic mode.

In this work, preliminary oil pollution hazard maps are presented to identify the most/least impacted areas in the basin.

Hazard maps can be used to develop response and mitigation strategies as well as to support biodiversity conservation efforts, which is in line with the flagship NECCTON[1] project (New Copernicus Capability for Trophic Ocean Networks). In the project's framework, new operational tools and products are designing to strengthen the Copernicus Marine Service capability of modeling marine pollution.

Materials and Methods

The MEDSLIK-II[2] oil spill model [12] is a free-access community model that has been successfully used for more than 12 years to simulate the transport and fate of oil spills in both deterministic and stochastic modes. A full list of the published MEDSLIK-II applications can be found at the referred website. In the model framework, the oil slick is discretized into constituent particles. Each particle moves due to currents, wind, and waves, data on which are provided by external oceanographic and atmospheric models or observations. Subgrid processes that are not resolved in the meteo-oceanographic models are taken into account with the 'random walk' scheme. The oil transformation processes are calculated by means of the bulk formulae, which formalize the changes in the surface oil volume due to three main processes known collectively as weathering: viscous-gravity spreading, evaporation, and natural dispersion. The formation of water-in-oil emulsion is also taken into account. MEDSLIK-II simulates the interaction of oil with shoreline considering the probability that oil may be washed back into the water. At each time step, MEDSLIK-II computes the geographical coordinates of particles as well as oil concentrations at the sea surface, in the water column, and on the coast. The model allows the choice of oil types from the Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC) database composed of 225 constituents.

To force oil drift and transformations MEDSLIK-II requires the input of data about atmospheric wind, sea surface temperature, and sea currents. For the reconstruction of the *HAVEN* oil spill, we use the 6-hour wind speed data provided by the ERA5 reanalysis of 0.25° latitude-longitude grid (∼25 km in the Mediterranean). While for the stochastic MEDSLIK-II simulations, we use the 6-hour datasets provided by ECMWF at a 0.125° horizontal resolution (∼12.5 km in the Mediterranean). In both cases, we employ the Copernicus Marine Service daily oceanographic reanalysis data[3] on currents and temperatures with a horizontal resolution of 1/24° (~4 km) [14].

[1]https://www.neccton.eu (Accessed online: April 2024).
[2]http://medslik-ii.org (Accessed online: January 2024).
[3]https://data.marine.copernicus.eu/product/MEDSEA_MULTIYEAR_PHY_006_004 (Accessed online: April 2024).

In accordance with historical records, on April 11th, 1991, while the Very Large Crude Carrier (VLCC) *HAVEN* was anchored in front of the Port of Genoa, two violent explosions started a fire within the ship that was extinguished only 70 – 99 hours later when *HAVEN* sunk. At the moment of the disaster, which killed six crew members, 144 000 tons of heavy Iranian crude oil and 1 223 tons of fuel oil and diesel were on board. The vessel broke into three sections with one section sinking close to the anchor location. A large quantity of burnt oil rapidly sank in form of bitumen, while the rest of the cargo was transported by currents and waves in the densely populated coastal region of the Liguro-Provençal basin.

During the emergency phase, two important decisions were taken: to tug the remaining main ship section coastward and to allow the burning of the greatest part of the oil spilled at sea.

An environmental assessment of the affected region indicated the injury from the spilled oil to subtidal *Posidonia*/*Cymodocea* (seagrass) beds, the deep-sea benthic community and associated commercial fisheries [15]. Although recovery typically takes place within one to three years [16], a restoration program was on the way 12 years later mainly dealing with the tar residuals laying on the seabed and with the oil products still contained in the wreck.

We specify the *HAVEN* oil spill scenario based on [15, 17–19] as follows:

- starting time of the spill is 11th April 1991 12:30 pm;
- initial spill coordinate is 44°20’N, 08°45’E;
- the continuous 50-hour release with a spill rate of 200 ton/hour gives the total spilled oil volume of 10 000 tons;
- the type of the oil is heavy Iranian crude oil (API = 31);
- the simulation length is chosen to be 432 hours (18 days) until 29th April, when the last spill observations arrived;
- the Stokes drift is taken into consideration by means of the empirical JONSWAP wave spectrum as a function of wind speed and fetch.

The 26 field detections 11 April – 29 April 1991 composed of the point- and segment slicks provided courtesy by Météo-France are used for the model restarts (Fig. 1).

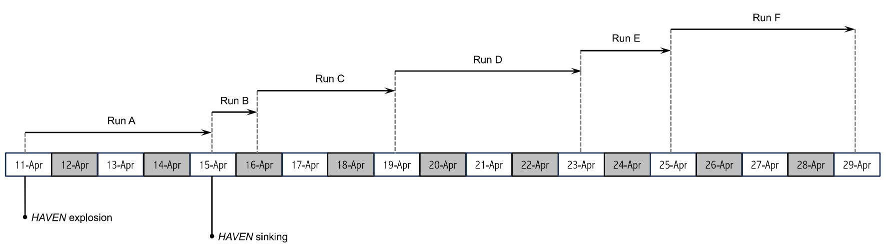

Figure 1 – Timeline of the observations (dotted vertical lines) and the MEDSLIK-II restarts (horizontal arrows Run A ÷ Run F).

If the exact times of observation are not available, we use the best-in-time hours to calculate the performance metrics.

For the stochastic simulations, we use almost the same scenario applying randomization to starting time and locations. The simulation length is chosen to be 600 hours (25 days) assuming that such a long-lasted tracking is enough for the oil to reach the coastlines or to be removed from the surface by weathering.

To account for the slow weathering processes as biodegradation, photooxidation, etc., we have modified the MEDSLIK-II code adding a simplified first-order oil decay term with a constant rate of 0.04 day^{-1} [20].

To reduce computation time in stochastic mode we apply a 1 % windage coefficient instead of the JONSWAP-based Stokes drift; and we decrease a default number of Lagrangian particles of 100 000 to 40 000.

In contrast to temporal randomization, which type does not have a critical impact on the final hazard maps, spatial randomization of virtual spill sources is crucial. Considering our previous experience, we expected hazard indices to correspond to the distributions of the oil spill sources with some spatial distortion controlled by the meteo-oceanographic conditions in the basin.

At the pre-processing stage, an original seeding algorithm (Fig. 2a–d) has been developed starting with a cumulative spatial distribution of oil slicks (Fig. 2a) detected by the Sentinel- 1A/1B synthetic-aperture radars [13].

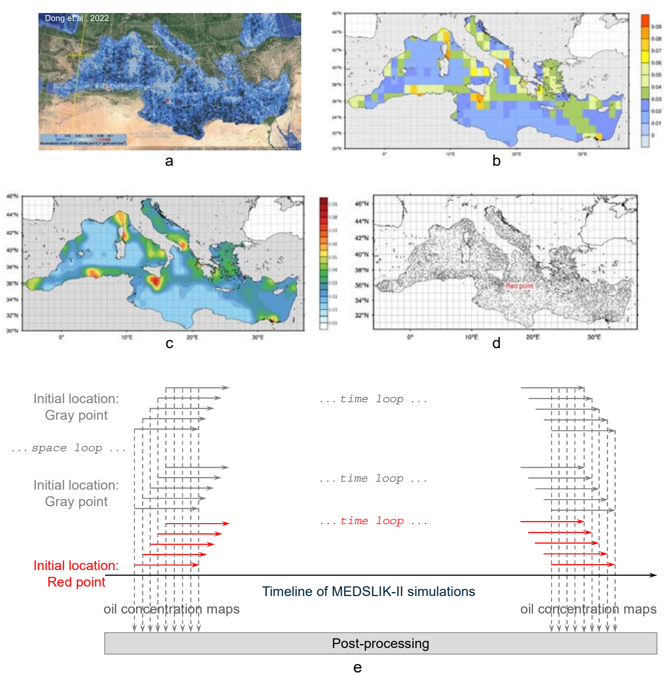

Figure 2 – Workflow elements for the MEDSLIK-II stochastic simulations: seeding algorithm (a–d) and two primary loops: over the time 2018–2021 and in space covering all the initial locations generated in (d).

The map (Fig. 2a) is digitized manually into a 1° resolution map (Fig. 2b) followed by re-gridding to a 1/24° resolution by optimal interpolation (Fig. 2c). This map is used for stratified sampling the initial spill locations (Fig. 2d). Running MEDSLIK-II in batch mode, we perform two basic loops: through the time 2018–2021; and in space, covering all the initial spill locations depicted in Fig. 2d as an example (Fig. 2e).

Among others, our approach has inherited a critical limitation from the radar-derived detection methodology, which states that the optimal wind speeds for oil slick detection range from ~1.5 to 10 m s^{-1}.

We assume that the resulting bias is not very big since the NCEP wind speed statistics in the Med shows that the mean ± STD occurrence frequencies of the low wind speeds (< 1.5 m s^{-1}) are 0.09 ± 0.09 and of the high wind speeds (> 10 m s^{-1}) are 0.08 ± 0.07 [13].

Ironically, the major oil spills in the Mediterranean, such as the *HAVEN* and *ULYSSE*/*VIRGINIA* (the NW Mediterranean, 2018) incidents, *JIYYEH* Power Plant (Lebanon, 2006) and *BANIYAS* (Syria, 2021) Power Plant oil spills started exactly under the low-wind conditions, in contrast to the Atlantic oil spills. So that, the early stages of those spill developments could be hardly visible to radars.

The simulation results are represented by a sample composed of a huge number of virtual spills constituted of the hourly oil concentration fields. In accordance with [8], we impose on them a threshold of 0.1 ton km^{-2} to separate the hazardous sea surface oil concentrations from the non-hazardous ones. Then, to obtain hazard indices in probabilistic terms we normalize the resulting distribution to the total number of virtual spills. Hazard indices clearly range between 0 and 1, where 1 indicates maximum hazard and 0 no hazard.

Results and Discussion: reconstruction of the *HAVEN* oil spill

A common assumption is that computed oil pathways tend to accumulate errors over longer distances and time due to intrinsic model simplifications. Restarting MEDSLIK-II with updated observational patterns, we believe that the effects of hindcast error growth could be implicitly accounted for and minimized.

Generally, the model realistically represents the oil drift in the SW direction with significant stretching along the coastline from Genoa to Fréjus (Fig. 3).

This movement is mainly controlled by the Northern Current with the peak velocities of 0.6÷0.8 m s^{-1} in front of Imperia. However, we could not improve the MOTHY[4]-based simulations of slick trajectory [19] despite the expected progress related to the enhancement in the resolution of currents, both spatial (4 km *vs* 6.5 km) and temporal (daily *vs* monthly). Moreover, MEDSLIK-II could not represent the backward movement of oil on 29th April 1991 (Fig. 3, 4). Underlaying model-based hydrodynamics shows a complicated cascade of short-lived mesoscale eddies (mainly anticyclonic) generated on the continental slope. But probably, these eddies are falling short in capturing the complexity of observed oil drift. The main reason might be related to the existing drift model parameterizations, which are to a

[4] http://www.meteorologie.eu.org/mothy/index.html (Accessed online: May 2024).

large degree based on laboratory measurements that are not always representative of field conditions.

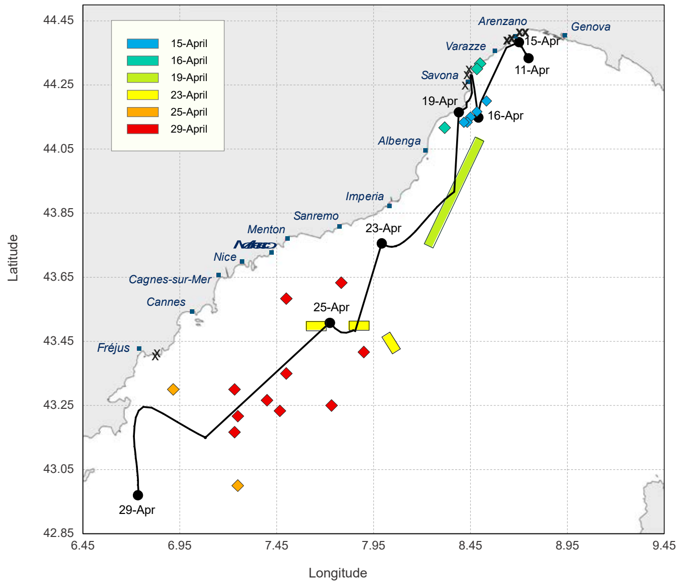

Figure 3 – Model-based oil drift (black curve) and the observations (colorful patterns); bold crosses show the massive oil beaching (>1 ton km^{-1}), while regular crosses depict the medium beaching (</= 1 ton km^{-1}).

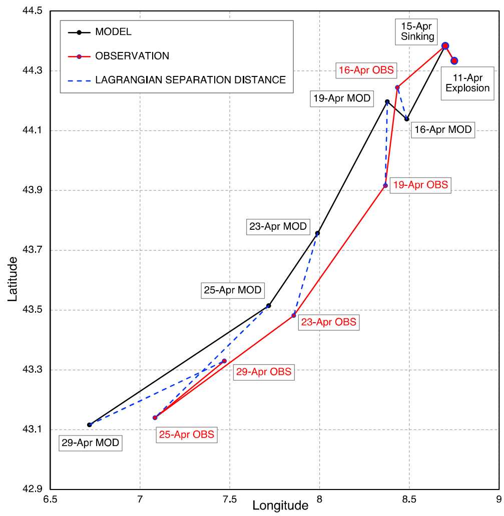

Figure 4 – Model (in black) and observation (in red) mass center trajectory, and the Lagrangian separation distances (in dotted blue segments).

Our simulations confirm a big quantity of oil arrived to the Arenzano beach as well as some oil accumulated ashore between Varazze and Savona (Fig. 3).

On the other hand, the modelled slick too quickly approaches towards the coastline causing the excessive beaching (e.g., east of Fréjus), which was not confirmed by observations.

Lagrangian separated distances applied to the center mass trajectory show quite large values, growing in time from ~12.5 km on April 16th to ~67.7 km on April 29th, (Fig. 4) and pretty poor Liu-Weisberg skill scores (0 ÷ 0.61).

Further efforts are needed to refine both underlying hydrodynamics and oil drift and weathering parameterization in MEDSLIK-II.

Results and Discussion: stochastic simulations of the *HAVEN* oil spill

We sample a great variety of virtual spill trajectories 2018–2021 (e.g., Fig. 5).

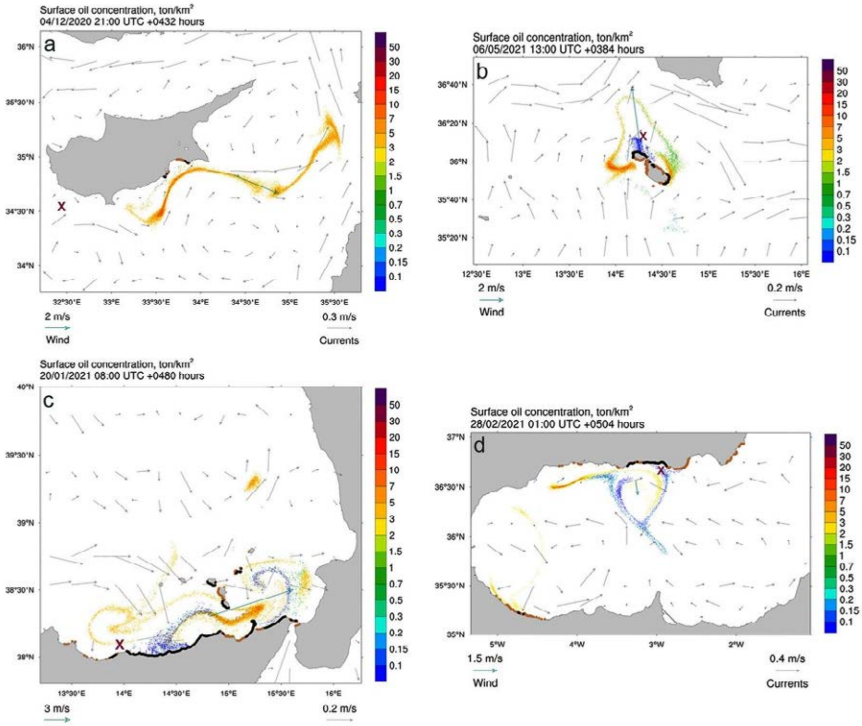

Figure 5 – Snapshots of some virtual spills started 04/12/2020 21:00 near Cyprus (a); 06/05/2021 13:00 in the Malta bunkering area (b); 20/01/2021 08:00 near Sicily (c); and 28/02/2021 01:00 in the Spanish coastal area (d). Pink crosses mark the start locations. The wind vector corresponds to the center of mass of the slick. Beached oil at concentration < 1 ton km^{-1} is depicted in brown, >/= 1 ton km^{-1} – in black.

Depending on currents and winds, the spill may cover large sea areas (Fig. 5a, d) or may develop locally (Fig. 5b, c). In the NE Levantine, a virtual spill is entrapped by a vortex dipole that is clearly visible in Fig. 5a. Genesis of such kind of structures seems to be typical of these waters [21]. In case of a slick seeded in the vicinity of the Malta bunkering area, the currents and wind are relatively weak. Therefore, almost the whole coastlines of the neighboring islands are contaminated by oil (Fig. 5b). Being driven by complicated coastal hydrodynamics, a virtual slick seeded near Sicily (Fig. 5c) reveals multiply re-suspensions and splitting into the small-scale patterns. In the Alboran Sea, a large spill can quickly contaminate both the northern and southern coastlines due to very energetic circulation (Fig. 5d).

Post-processing the acquired statistics allows us to map the pollution hazard indices at the Mediterranean surface.

Accomplishing the stochastic simulations, we should be confident that the number of virtual spills is large enough to obtain a reasonably accurate hazard map. Convergence of our method is based on the law of large numbers, which indicates that repeated sampling will result in the average outcome converging towards 'the true solution'. Remarkably, the optimal number depends on the basin geometry, meteo-oceanographic conditions, and initial distribution of spill sources. To determine this number we monitor the variability of hazard maps progressively increasing number of virtual spills. Initially, the maps showed many discontinuous patterns (Fig. 6a), but eventually the solution converge to a quite smooth hazard distribution, which is stable as the number of spills increased. We have found that ~1 200 000 virtual spills are enough to achieve stationary hazards that almost do not change with further number increasing.

Analyzing the final hazard map (Fig. 6b), we note that the hazard indices range up to 10^{-2}, which is typical of the smoothly distributed initial oil spill sources [5]. On the contrary, the hazard values asymptotically approaching 1 are usually obtained in case of a point-source associated, for example, with an oil production platform [7]. Spatial patterns of hazards over the Mediterranean tends to correspond to the initial spill sources (Fig. 2a–d). Distinctive 'hot spots', where the values of hazard indices exceed $5.6 \cdot 10^{-3}$, are clearly visible in the Algerian subbasin and the eastern Alboran Sea, in the Liguro-Provençal subbasin, and in the center of the Ionian Sea.

Conversely, the southern part of the Ionian, the areas east of Sardinia and west of Corsica, the Gulf of Lion, the northern Adriatic, and north-eastern Aegean Sea do not reveal high hazards. Intermediate values of hazard indices ranged $3.2 \cdot 10^{-3} \div 4.8 \cdot 10^{-3}$ are found in the Balearic Sea, in the northern Tyrrhenian, eastern Ionian and the entire Levantine. Interestingly, the shape of the largest hazard areas is following the climatological paths of the principal currents including the Algerian Current, Eastern Alboran Gyre, Northern Current, and the Atlantic-Ionian Stream. The connection with other sea surface currents is visible, e.g., with the Western Adriatic Coastal and Eastern South-Adriatic Currents, as well the Asia Minor Current.

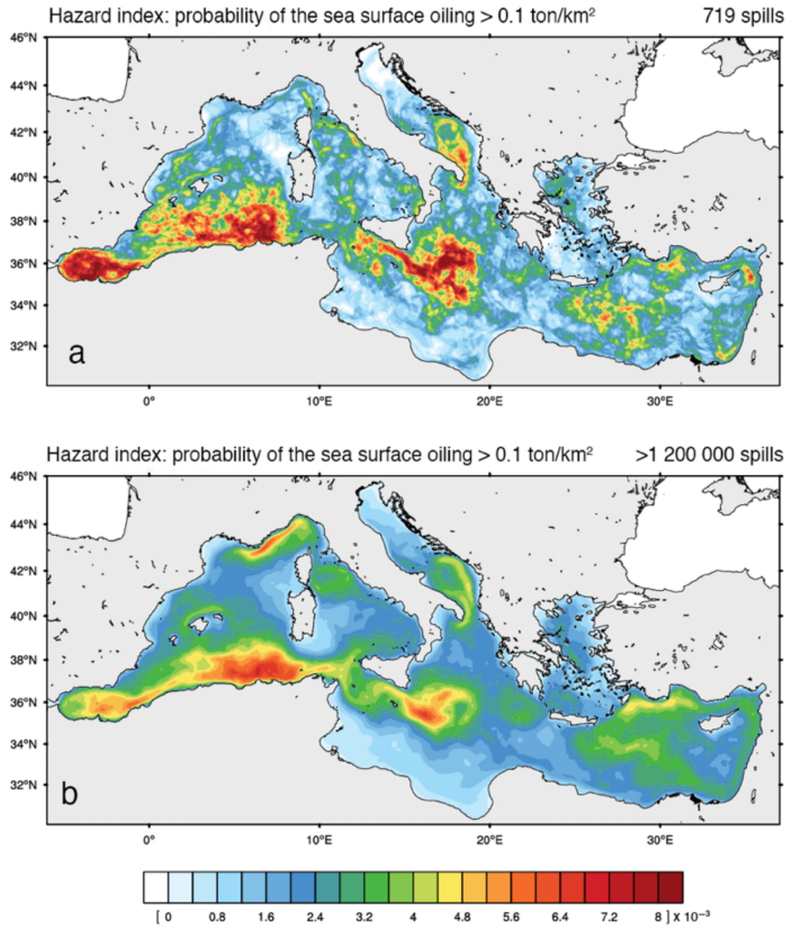

Figure 6 – Convergence to the stationary 'true solution': (a) hazard map acquired from 719 virtual spills; and (b) from > 1 200 000 ones.

Conclusion

In this work, we focus on the *HAVEN* oil spill occurred in April 1991 off the Genoa Port which is considered a 'high-impact low-probability' accident. The total cost of this disaster to the entire Mediterranean ecosystem may never be fully recognized.

We have reconstructed this historical spill with the Lagrangian oil spill model MEDSLIK-II forced by the contemporary high-resolution meteo-oceanographic datasets. Although we obtain quite a consistent general direction of the oil movement, we could not improve the results computed earlier with the MOTHY model suite [17]. This fact confirms that enhancing the hydrodynamic model resolution does not always lead to better performances in the coupled Lagrangian particle tracking [22]. Further efforts are needed to improve the MEDSLIK-II parameterizations.

Thereafter, we launch the stochastic oil spill simulations of the *HAVEN* spill scenario to map oil pollution hazard indices in case a similar large oil spill happens in the Mediterranean in the future. The hazard map obtained can be considered a multiyear product that will be delivered to the NECCTON project. This map is representative of future accidents as we can assume that the oil source distribution is representative of the present state and the used meteo-oceanographic datasets contain a realistic sample of possible weather and sea state conditions.

Hazard indices show the elevated values in the Algerian subbasin and the eastern Alboran Sea, in the Liguro-Provençal subbasin, and in the center of the Ionian Sea. Conversely, the southern part of the Ionian, the areas east of Sardinia and west of Corsica, the Gulf of Lion, the northern Adriatic, and north-eastern Aegean Sea do not display high hazards.

Hazard maps computed in this work are of relevance mainly to practitioners: agencies providing oil spill monitoring and organizations engaged in oil spill contingency and preparedness planning.

Acknowledgements

This work is performed in the framework of the NECCTON project (grant number 101081273).

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MODELING OF FLOW PATTERNS AND MICROBIOLOGICAL PARAMETERS FOR HAZARD ASSESSMENT OF BATHING WATERS AFFECTED BY COMBINED SEWER OVERFLOWS

Giuseppe Locuratolo, Elvira Armenio, Enrico Barbone, Cosimo Giannuzzi, Antonietta Porfido, Nicola Ungaro

Abstract: ARPA Puglia carried out a numerical study to simulate the evolution of the turbidity plume geometry and to describe the bacterial dispersion caused by the discharge of a mixture of raw sewage and surface runoff from the so called *condotta Matteotti* into the marine-coastal waterbody close to the urban beach (bathing area) called “Pane e Pomodoro”. The *condotta Matteotti* is an underground concrete pipe connected with a spillway to the main sewer system: it acts as an emergency weir to prevent flooding during or soon after intense rainfall events. During these rainfalls the seaward sluice gates open, and the untreated sewage is discharged into the sea thus decreasing the water quality. The simulation, according to a heavy rainfall and overflow event occurred in July 2018, was implemented using the DHI's Mike 3 suite enhanced with the ECOlab module, both organized as step-by-step processes. The validation of the final model was performed by comparing the microbiological concentration resulted from the model application with the on-field measurements and samples collected by ARPA Puglia during its ordinary water monitoring activities.

Keywords: overflow, bathing waters, water quality, flow pattern, bacterial dispersion

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Giuseppe Locuratolo, Elvira Armenio, Enrico Barbone, Cosimo Giannuzzi, Antonietta Porfido, Nicola Ungaro, *Modeling of flow patterns and microbiological parameters for hazard assessment of bathing waters affected by combined sewer overflows*, pp. 923-933, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.80

Introduction

Bathing water quality can decrease significantly due to sewage and surface runoff overflows after huge rainfalls [1] [2].

The town of Bari (close to 330 000 inhabitants) is located on the south-western Adriatic coast, and mostly of the raw sewage waters are collected and treated by two large wastewater treatment plants. Nevertheless, in the southern part of the town the drainage system is mixed, collecting both wastewater from civil settlements and urban runoff into the same underground sewage system that, during or soon after intense rainfall events, activates the emergency overflow discharge from the pipe "*condotta Matteotti*" close the urban beach of "*Pane e Pomodoro*".

The *condotta Matteotti* is a buried channel used as an emergency weir, connected to the main network with a spillway and proceeding straight towards the Nazario Sauro seafront (Figure 1), where sluice gates are located seaward.

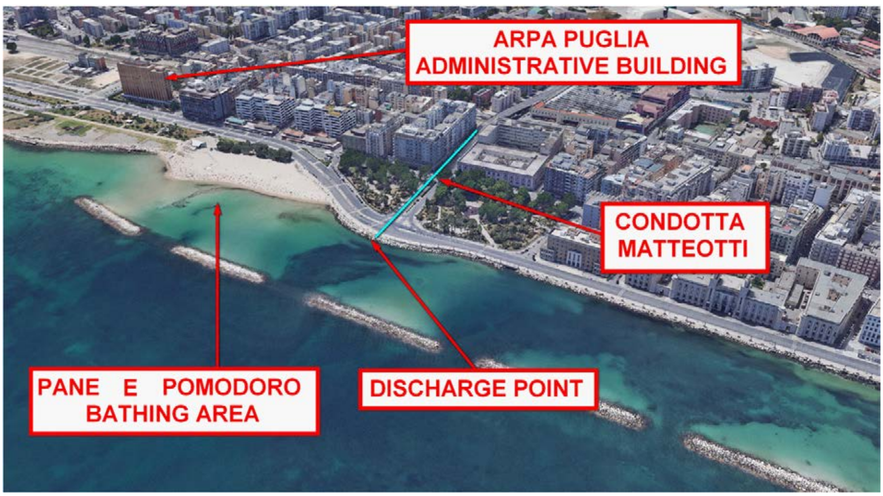

Figure 1 – Panoramic view of Bari's southern waterfront.

Due to the accumulation of rainfall, once the flow rate into the main network reaches about 250÷300 L s^{-1}, the mixture of runoff water and raw sewage rises above the crest of the spillway and begins to be released into the channel. When the water accumulated in the channel rises up to a level of 70 cm, the sluice gates automatically open and the water is abruptly discharged with its untreated bacterial load at the sea.

The discharge of the mixed water produces a turbidity plume (Figure 2) dispersing its bacterial content at the sea according to the current regime at the time. Subsequently, the Municipality of Bari issues an order for a temporary bathing closure in the *Pane e pomodoro* area, one of the most crowded beaches on Bari's urban coastline, until ARPA Puglia verifies the restoration of bathing water quality standards according to the limits defined by Italian laws (Italian Legislative Decree n. 116/2008).

The sewage outflows generally occur during or soon after intense and time-concentrated rainfalls: it was verified that even rainfall events lasting one hour or less may be sufficient in case of heavy rain [3].

This study, in particular, was focused on reproducing the geometrical spreading of the plume fronts, including its bacterial concentration, over time, triggered after the discharge event started on July 23rd, 2018: this event was also recorded by ARPA Puglia with video and photos.

Figure 2 – Turbidity plume recorded on July 24th from the ARPA Puglia administrative building.

Study area

The simulation involved an enlarged marine area of 12 x 15 km.

In this area, the hydrodynamic regime close to the coastline is strongly influenced by the presence of two ports (the new port structures much bigger than the old-historic one) and wave defence structures.

In particular, a defence system consisting of 10 emerged breakwaters (on average 10 meters wide and 150 meters long) run parallel to the shoreline, with a top berm about 1 meter above the mean sea level. Moreover, concrete blocks protect as wave attenuators the seafront road.

The discharge point of the *canale Matteotti* is located approximately 200 meters north-west of *Pane e Pomodoro* beach and less than 1 km south-east of the old port.

Materials and Methods

The simulation was carried out step by step. The first step was the implementation of the hydrodynamic model by using the three-dimensional flow model MIKE 3 [4].

A large mesh in the offshore water zone, appropriately nested in the study area, was used to discretize the domain. The nodes of this mesh represent the calculation points of the model (Figure 3).

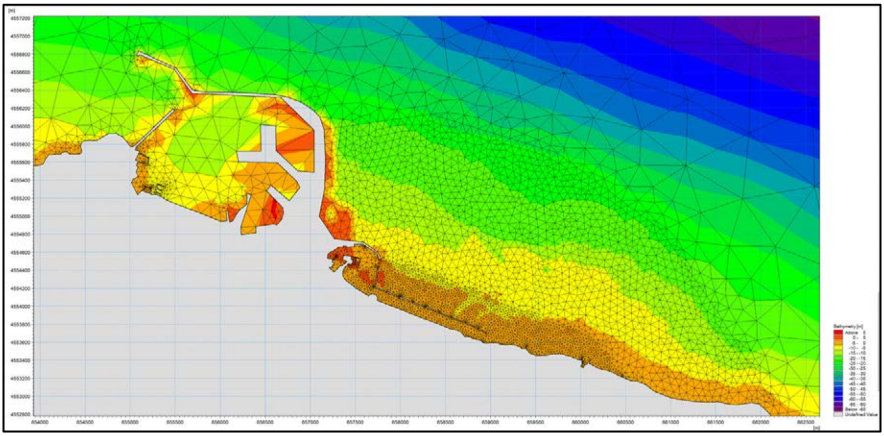

Figure 3 – Triangular shaped mesh and bathymetry to compute the hydrodynamic model

Once the mesh was created, the set-up window was filled with two main digital records: weather time series and sea state conditions at regional scale.

The weather time series of temperature, atmospheric pressure, humidity, rainfall, wind speed, wind direction and solar radiation were collected by the meteorological control unit located at the ARPA Puglia headquarters, located close to the beach.

The rainfall time series from May to October 2018 is shown in Figure 4: the red triangle highlights the events that forced the opening of the sluice gates, including the event of July 23rd, 2018.

The analysed rainfall time series provides twofold information:

- the precipitation rate for a single weather event causing the opening of the floodgates is highly variable, from around 18 mm/h to less than 2 mm/h;
- there is no minimum rainfall limit above which the sluice gates are opened.

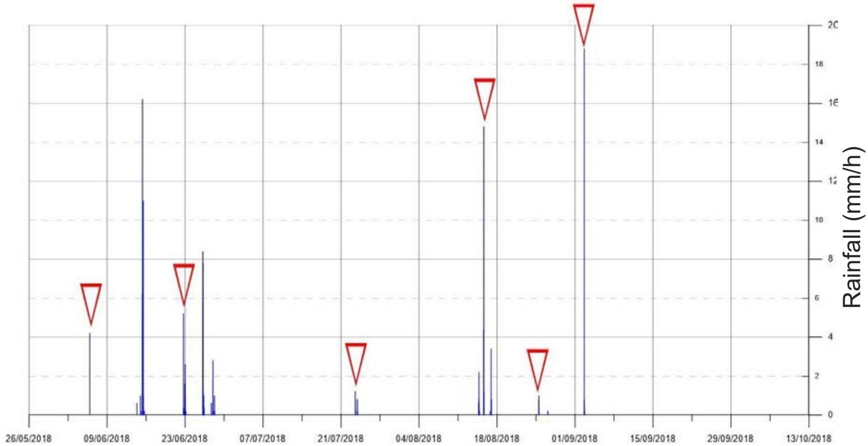

Figure 4 – Rainfall time series (mm) from 26/05/2024 to 13/10/2018: the red triangles show the weather event triggering the discharge activation (including the event of July 23rd, 2018).

The downscaling from regional to local sea circulation was based on the data available from the Copernicus Marine Service[1], which provides free, regular and systematic information on the state of the sea (wave, current, temperature, atmospheric pressure, etc..) on a regional scale.

The set-up was completed using the bathymetric model downloaded from the EMODnet portal[2] and the tidal data obtained from the National Tidal Network (RMN) managed by ISPRA, for the tide station located in the port of Bari (the computing period was the whole month of July 2018).

Different and time-consuming runs were completed to fix any failures. In the end, the hydrodynamic model was finalized, and the local sea circulation was reproduced as the main output (Figure 5).

After that, the *ECOLAB Entorococci* and *E. coli* module was coupled with the hydrodynamic model in order to simulate the simultaneous processes of bacterial transport and dispersion. The decay processes describing the decrease of the two bacteria in time and space are dependent on factors such as the salinity, water temperature, and the solar radiation: these parameters were directly achieved from the hydrodynamic model, whereas the flow rate in the discharge point and the initial bacterial content were provided by the *Acquedotto Pugliese* water service company[3]. The decay model adopted is described by *Erichsen et alii* [6]. For the bacterial transport and dispersion, the simulation of the spillage started at 11 p.m. on the July 23rd, 2018, when the sluice gates effectively opened, assuming that the discharge lasted 1 hour.

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[1] https://marine.copernicus.eu/

[2] The European Marine Observation and Data Network (EMODnet) is the European Commission (EC) in situ marine data service (https://emodnet.ec.europa.eu/en)

[3] www.aqp.it

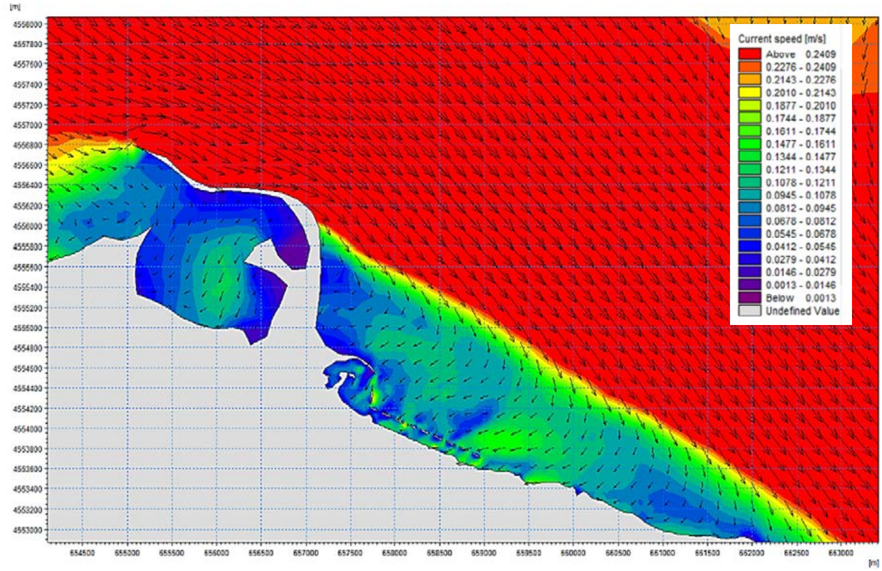

Figure 5 – Sea surface currents circulation on the July 24th, 2018, at 10.00 a.m. (after three days of computing).

Results and discussion

The validation of the hydrodynamic model was performed comparing the physical parameters measured by the model and the values measured by ARPA Puglia during the institutional monitoring of the bathing waters in the period April – September 2018.

In particular, time series were extracted from the hydrodynamic output of the Mike 3 model at the same positions monitored by ARPA Puglia, named T1, T2 and T3. The average value of sea surface temperature calculated by the model was 24.7 °C (averaged over the time interval), which well fit with the values measured in field (approximately 24.4 - 25.6 °C). The average velocity values of the surface currents from the numerical model were 0.093 m s^{-1} at point T1, 0.079 m s^{-1} at point T2 and 0.068 m s^{-1} at point T3, respectively. The range of the model's current velocity values for the overall simulation period varies from 0.01 to 0.3 m s^{-1}. Also in this case, the comparison with the surface current velocity values measured during the ARPA Puglia bathing waters monitoring (2018) shows the same order of magnitude.

The ECOLab module produced the simulation of the bacterial concentration over time, and the results are reported in the maps showed in the Figures 6,7, 8, 9, 10 and 11, corresponding respectively to the scenarios at time steps of 3 hours each other.

Looking at the same maps, and assuming the law limit of 200 CFU mL^{-1} for the Enterococci, the simulation highlights that, according to the local sea current regime at the time, the bacterial content discharged from the *canale Matteotti* affected the compliance of the bathing area *Pane e Pomodoro* only for twelve hours after the overflow event. This means that the bathing quality standards were restored in less than one day. Moreover, the geometry of the plume as simulated by model is very similar to the effective geometry recorded in field by ARPA Puglia at almost the same time (Figure 12).

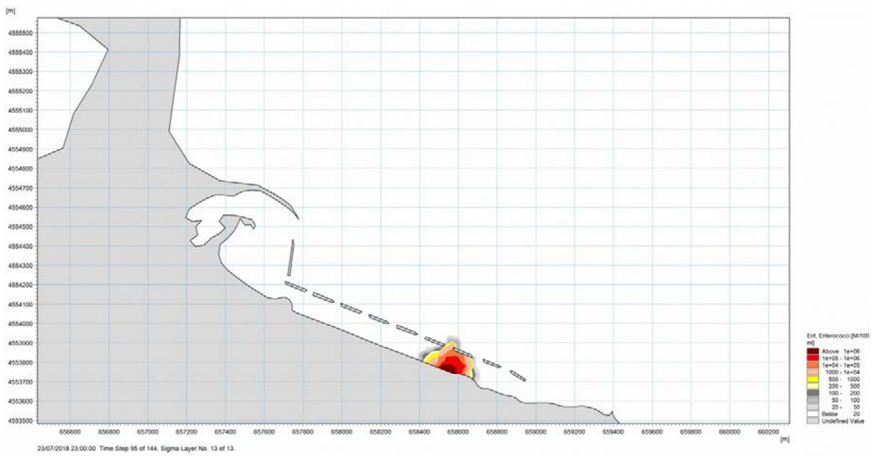

Figure 6 – Bacterial concentration plume at about 11.00 p.m. on July 23rd, 2018.

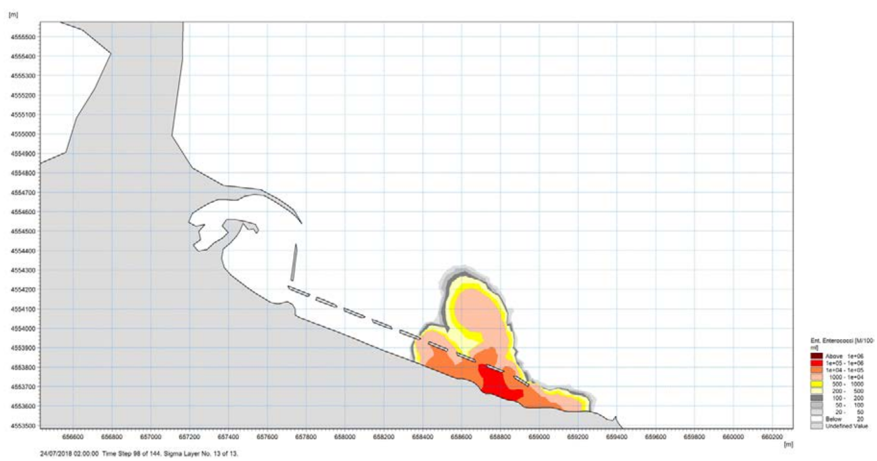

Figure 7 – Bacterial concentration plume at about 02.00 a.m. on July 24th, 2018 (3 hours after the opening of the sluice gates).

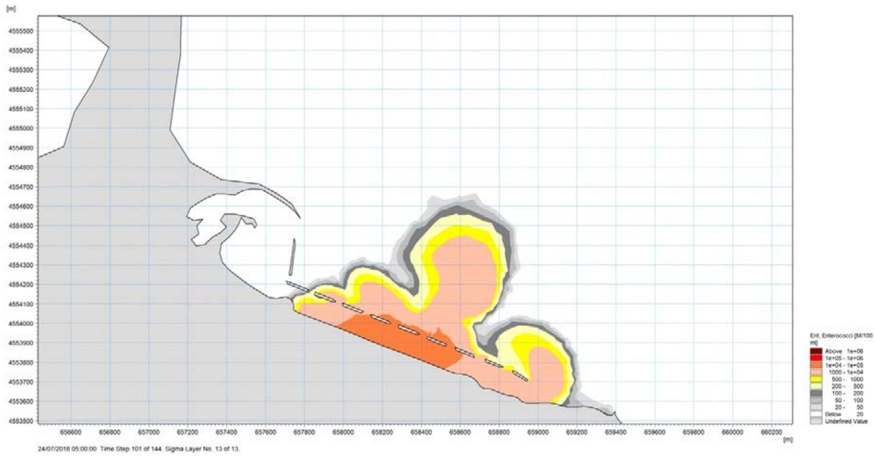

Figure 8 – Bacterial concentration plume at about 05.00 a.m. on July 24th, 2018 (6 hours after the opening of the sluice gates).

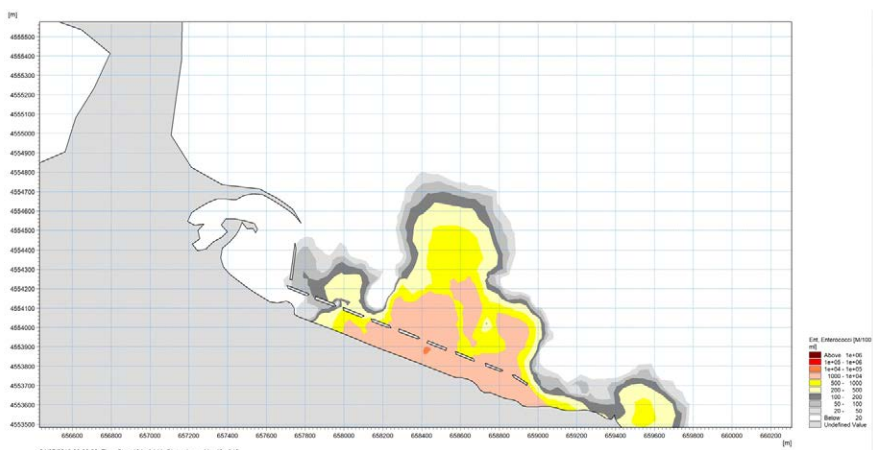

Figure 9 – Bacterial concentration plume at about 08.00 a.m. on July 24th, 2018 (9 hours after the opening of the sluice gates).

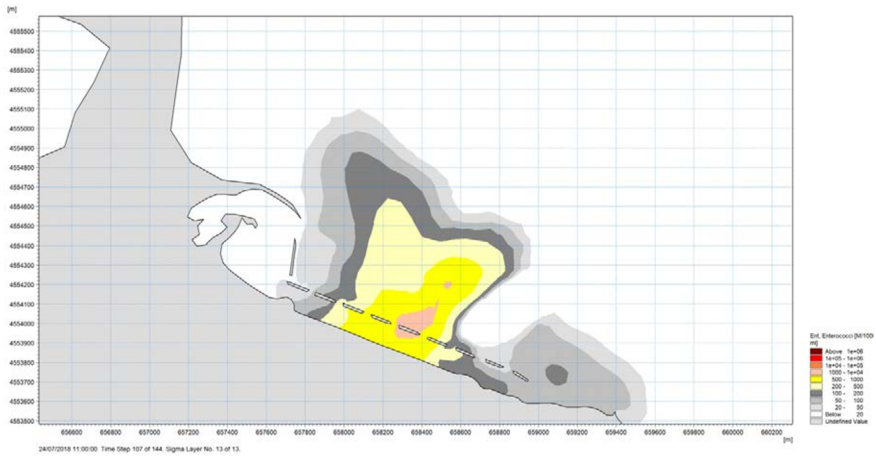

Figure 10 – Bacterial concentration plume at about 11.00 a.m. on July 24th, 2018 (12 hours after the opening of the sluice gates).

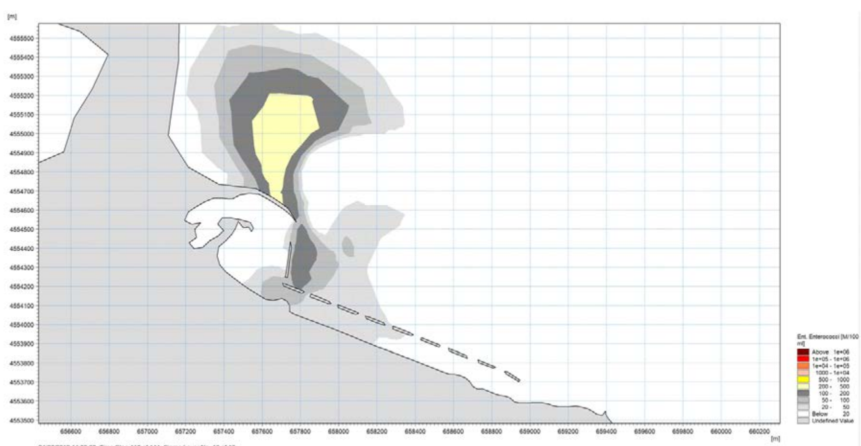

Figure 11 – Bacterial concentration plume at about 14.00 a.m. on July 24th, 2018 (15 hours after the opening of the sluice gates).

Figure 12 – Reconstruction of the geometry of the plume using the images taken by ARPA Puglia at about 8.00 a.m. of July 24th, 2018.

Conclusion

In the present study was simulated the dispersion of the turbidity plume and its bacterial content from the discharge of the emergency outflow *condotta Matteotti* in Bari, during and immediately after a heavy rainfall.

The simulation was performed by applying the MIKE 3 software, which combines the ECOLab module with the hydrodynamic model, in order to reproduce the effects of the short-term pollution on bathing water close to the emergency weir of the main drainage system. The results revealed a good comparability between the outputs of the model and the values measured in-field by ARPA Puglia during its ordinary monitoring activities, both for hydrodynamic and microbiological aspects. However, although the modelling application has provided a reliable picture, it must be noted that some of the features involved suffer a lack of information. For example, the deficit in the time and spatial coverage at local scale of the oceanographic data (wave and current parameters) should be overcome, and a high-resolution bathymetric model is needed for the area closest the coast.

In any case, the hydrodynamic model used to simulate the spreading of the bacterial concentration plume can be considered as a useful tool for the early warning system, in order to identify a possible short-term pollution and the subsequently mitigation actions (i.e. estimation of bathing closure period), as it was also suggested by the European Directive 7/2006/EC (Bathing Water -BWD).

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SALINATION OF SPRINGS IN THE BAKAR BAY

Davor Mance, Lucija Brevulj, Diana Mance

Abstract: Rising sea levels, increasing air temperatures, and recurring extreme weather events make coastal freshwater more susceptible to salination. This study investigates the relationship between salinity in the Perilo, Dobra, and Dobrica springs in the Bay of Bakar (Croatia) and extreme weather events from June 2005 to June 2020.
Panel analysis, including water temperature (°C), electrical conductivity (μS/cm), hardness (mg/L $CaCO_3$), and chloride (mg/L), showed significant positive correlations between water temperature and chloride content, as well as direct relationships between electrical conductivity and chloride concentration. The study emphasizes the influence of weather on spring salinity and underscores the need for climate change adaptation strategies and sustainable water resource management. The findings hold significant implications for policymakers and stakeholders in water resource management.

Keywords: climate change, springs salination, coastal environmental physics, analysis. of economic environmental impacts.

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Referee List (DOI 10.36253/fup_referee_list)
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Introduction

The salination of freshwater sources is a growing problem in coastal regions around the world, caused by rising sea levels, increasing air temperatures, and extreme weather events [1]. The Bay of Bakar in Croatia is no exception. Understanding the salination process in this region is crucial as it affects the availability and quality of drinking water, which is essential for the local population and the health of the ecosystem. The principles that govern the infiltration of saline seawater into freshwater aquifers are summarized in the Ghyben-Herzberg relationship:

$$z = \frac{\rho_s}{(\rho_m - \rho_s)} \cdot h \tag{1}$$

In which (Fig. 1): z is the depth of freshwater below sea level, h is the height of freshwater above sea level, ρ_s = 1000 g/cm^3 is the density of freshwater at 20 °C, and ρ_m = 1025 g/cm^3 is the density of seawater. Since saltwater is denser than freshwater, a pressure gradient is created that favors the penetration of saline seawater into freshwater aquifers and ultimately leads to the salinization of springs.

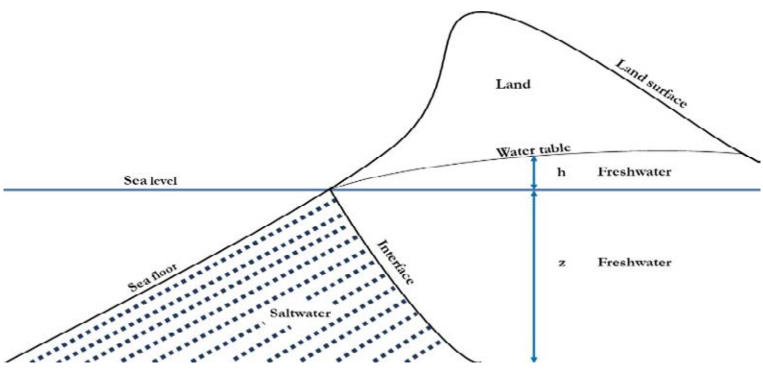

Figure 1 – Salinization of groundwater springs as a Ghyben-Herzberg relationship.

This hydrostatic principle explains that a combination of drop in the groundwater level and higher density of salt water leads to seawater penetrating the freshwater reserves. This process creates a pressure gradient that drives salt water into the coastal aquifers and leads to the salinisation of the springs. In regions such as the Bay of Bakar, this phenomenon poses a significant threat to freshwater resources, especially in times of drought or low rainfall.

The main objective of this study is to investigate the relationship between the salinity of the springs of Perilo, Dobra, and Dobrica in the Bay of Bakar and various extreme weather events recorded from June 2005 to June 2020. In particular, the study aims to answer the following research questions:

1. What are the main variables that contribute to changes in salinity?
2. What are the implications of these findings for climate change adaptation and sustainable management of water resources in coastal areas?

We have already visited the three springs when we analyzed the bacterial contamination of the marine water and stable isotope composition of water at these springs [2]. Through a comprehensive panel analysis of variables such as water temperature, electrical conductivity, water hardness and chloride concentration, this study will provide valuable insights into the dynamics of freshwater salinisation at the three springs. The results will help policy makers and stakeholders to implement effective strategies to mitigate the negative impacts of climate change on freshwater resources.

Materials and Methods

The main focus was on analyzing the relationship between extreme weather events and the salinity of drinking water sources in the Perilo, Dobra, and Dobrica springs in the Bay of Bakar (Fig. 2).

In this study, data collected between June 2005 and June 2020 by the Water Supply and Sewerage Ltd. Rijeka were analyzed. The data set included chloride (mg/L), electrical conductivity (µS/cm), hardness (mg/L $CaCO_3$), and water temperature (°C). The time series of these parameters are shown in Fig. 3 - Fig. 6.

Figure 2 – The location of the Bakar Bay within the Kvarner Bay (Croatia).

Chloride concentration in Dobrica exceeded the safe values on a total of 24 days between 1999 and 2009, reaching a maximum value of 2470.4 mg/L. Due to high extreme values and the adjustment of variables to be commensurate with each other, we cut the panel to the timeline between June 2005 and June 2020 (Fig. 3).

Conductivity is directly related to the presence of dissolved salts, including chlorides. Higher chloride concentrations would contribute to increased conductivity in the springs, as observed in the periodic spikes corresponding to those in chloride levels (Fig. 3 & Fig. 4). Elevated temperatures and salinity can lead to increased dissolution of carbonate minerals, thereby increasing water hardness (Fig. 5).

Spikes in chloride levels, especially during high-temperature periods, may correlate with increased hardness (Fig. 6). Below you will find a description of the statistical tests we used to analyze this data.

Panel unit root (stationarity) tests

To ensure the reliability of the panel data, stationarity tests were performed, including Levin, Lin and Chu (LLC), Breitung, Im, Pesaran and Shin (IPS), Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP). These tests are used to determine whether the variables are stationary, i.e. whether their statistical properties remain constant over time, which is crucial for accurate econometric modelling. The tests consider individual effects, linear trends and use Newey-West bandwidth selection to deal with serial correlation and heteroscedasticity. Rejecting of non-stationarities in data permits the usage of the following test approaches. [3, 4, 5]

Hausman test

The Hausman test is employed to determine whether a fixed effects or random effects model is more appropriate for panel data analysis. This test evaluates if the unique errors are correlated with the regressors. If the errors are uncorrelated, the random effects model is preferred due to its efficiency. By comparing the fixed and random effects models, the Hausman test ensures the selection of the most suitable model, thus enhancing the validity and reliability of the results. [3, 4, 5]

Panel Discrete Threshold Regression

The Panel Discrete Threshold Regression (TR) is a statistical analysis tool that provides a simple but effective approach to understanding nonlinear relationships in data characterized by abrupt changes. This model is characterised by piecewise linear specifications and introduces regime switching that captures shifts in the relationship between variables when certain thresholds are exceeded. The TR model is particularly valuable when investigating scenarios in which the behavior of an observed variable changes in response to unknown or unobservable thresholds such as in our example the changes in salinization as a consequence of changes in temperature. [3, 4, 5]

Cointegration Tests

Cointegration tests were conducted to determine whether a long-term equilibrium relationship exists among the variables: chloride, conductivity, hardness, and temperature. The Johansen Fisher Panel Cointegration Test, which combines both trace and maximum eigenvalue statistics, was utilized for this purpose. The results indicated strong evidence of cointegration, rejecting the null hypothesis of no cointegration at all levels with p-values of 0.0000. This suggests that these variables move together over time, maintaining a stable long-term relationship despite short-term fluctuations. [3, 4, 5]

Chloride

Figure 3 presents the chloride concentration (mg/L) over a period from June 2005 to June 2020 for three different locations: Dobra, Dobrica, and Perilo.

The data indicates that Dobrica experiences significant fluctuations in chloride levels, often peaking sharply, while Dobra and Perilo maintain more stable and lower chloride concentrations throughout the observed period.

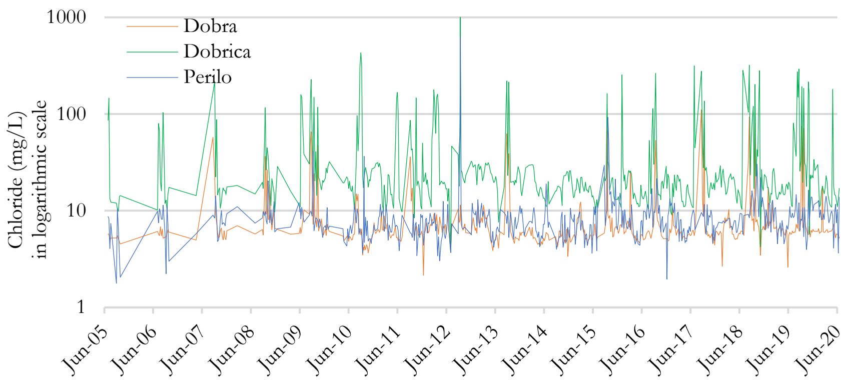

Figure 3 – Salination of Bakar bay springs measured in chloride concentration (mg/L in log).

Conductivity

Figure 4 presents the electrical conductivity (µS/cm) for same locations and time. The data indicates that again Dobrica experiences peaks in electrical conductivity, while Dobra and Perilo maintain more stable and lower conductivity levels throughout the observed period.

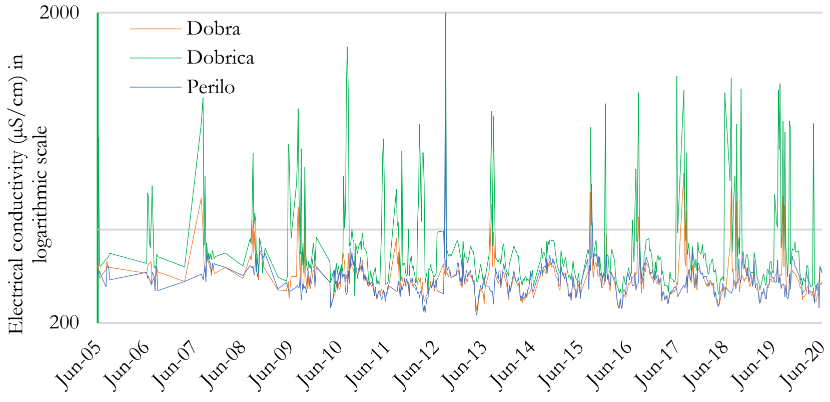

Figure 4 – Conductivity of Bakar bay springs measured in log scale of µS/cm.

Hardness

Figure 5 presents water hardness (mg/L of $CaCO_3$) for same locations and time. The data indicates that Dobrica shows significant fluctuations in water hardness, with several peaks, while Dobra and Perilo exhibit more stable and lower hardness levels throughout the observed period.

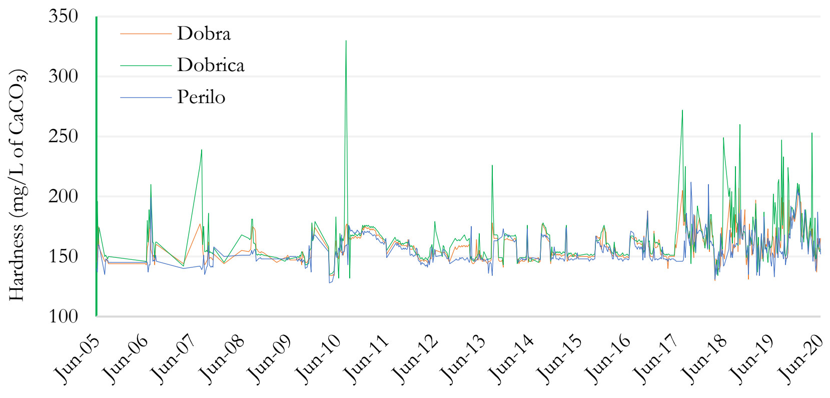

Figure 4 – Hardness of Bakar bay springs' water measured in mg/L of $CaCO_3$.

Water Temperature

Figure 6 shows the temperature measured in °C at the three springs at same dates. The diagram shows the temperature data and the trend lines for each location, indicating a significant increase in temperature during this period, especially after 2015. The trend lines show a consistent upward trend in temperatures for all three locations.

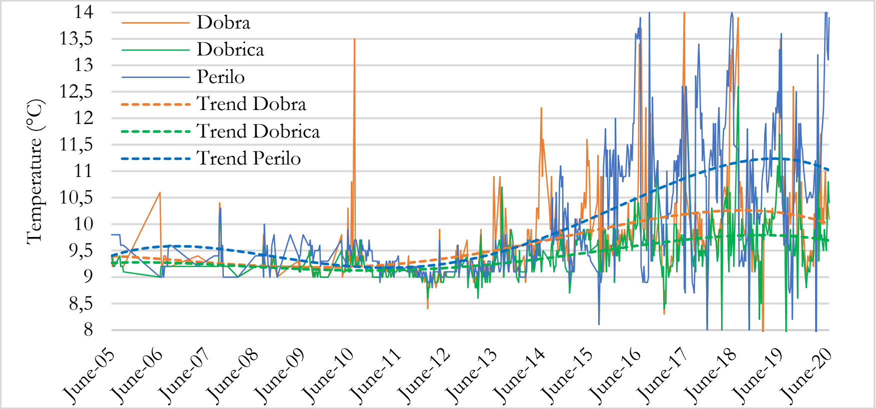

Figure 5 – Temperature of Bakar bay springs' water measured in °C.

Results

Panel unit root tests were conducted to assess the stationarity of the variables and the results are summarized in Table 1.

Table 1 – Panel unit root test: Summary.

Variable	Method	Statistics	Prob.	Cross-sections	Obs.
CHLORIDE	LLC	-22.1560	0.0000	3	1629
	Breitung	-14.3292	0.0000	3	1626
	IPS	-16.1426	0.0000	3	1629
	ADF	215.016	0.0000	3	1629
	PP	637.995	0.0000	3	1641
CONDUCTIVITY	LLC	-20.3214	0.0000	3	1629
	Breitung	-13.2416	0.0000	3	1626
	IPS	-14.2748	0.0000	3	1629
	ADF	178.199	0.0000	3	1629
	PP	490.885	0.0000	3	1641
HARDNESS	LLC	-15.1509	0.0000	3	1629
	Breitung	-8.96694	0.0000	3	1626
	IPS	-10.1439	0.0000	3	1629
	ADF	106.295	0.0000	3	1629
	PP	422.009	0.0000	3	1641
TEMPERATURE	LLC	-11.5181	0.0000	3	1629
	Breitung	-1.43126	0.0760	3	1626
	IPS	-10.5529	0.0000	3	1629
	ADF	111.885	0.0000	3	1629
	PP	447.092	0.0000	3	1641

Exogenous variables: Individual effects, individual linear trends. User-specified lags: 4. Newey-West automatic bandwidth selection and Bartlett kernel. Balanced observations for each test. Probabilities for Fisher tests are computed using an asymptotic Chi-square distribution. All other tests assume asymptotic normality.

Table 1 shows that all variables: chloride, conductivity, hardness, and temperature, are stationary, as indicated by the LLC, IPS, ADF, and PP tests ($p < 0.01$). Although the Breitung test for temperature has a p-value of 0.0762, the overall results confirm the stationarity of the data, supporting its suitability for further analysis.

The Hausman test was conducted to determine the appropriate model for analyzing the relationship between temperature, chloride concentration, Hardness, and Conductivity in the springs (Table 2). In contrast to ordinary least squares (OLS) regression, which estimates average effects, threshold regression (TR) provides insights into different regimes within the data based on specified thresholds. This method is beneficial for identifying non-linear relationships and abrupt changes in the effects of variables that are common in environmental data. Threshold regression provides a detailed understanding of the varying effects of weather variables on salinity, and can effectively capture the complex interactions and regime shifts in the salinisation process of springs.

Table 2 – Hausman test for temperature as an independent variable

Variable	Fixed	Random	Var(Diff.)	Prob.
CHLORIDE	-1.171309	-1.231331	0.001915	0.1702
CONDUCTIVITY	-6.396700	-6.618855	0.023949	0.1511
HARDNESS	0.869606	0.576539	0.003806	0.0000

Periods included: 548. Cross-sections included: 3. Total panel observations: 1644.

The results indicated that the random effects model is appropriate for chloride and conductivity (p-values > 0.05), while the fixed effects model is preferred for hardness (p-value < 0.05).

Table 3 – Pedroni Residual Cointegration Test Results

Test Statistics Name	Statistic	Prob.	Weighted Stat.	Prob.
Panel v-Statistic	-1.080370	0.8600	-0.883013	0.8114
Panel rho-Statistic	-138.5337	0.0000	-126.3353	0.0000
Panel PP-Statistic	-47.32854	0.0000	-43.45734	0.0000
Panel ADF-Statistic	-23.54387	0.0000	-21.08070	0.0000

Included observations: 1644. Cross-sections included: 3. Null Hypothesis: No cointegration.
Trend assumption: Deterministic intercept and trend. User-specified lag length: 1.

The results from the Pedroni test (Table 3), show mixed outcomes for the panel v-Statistic, which did not reject the null hypothesis of no cointegration. However, all other statistics (panel rho-Statistic, panel PP-Statistic, panel ADF-Statistic, group rho-Statistic, group PP-Statistic, and group ADF-Statistic) strongly rejected the null hypothesis ($p < 0.01$), indicating strong evidence of cointegration among the variables.

Table 4 – Johansen Fisher Panel Cointegration Test.

Hypothesized No. of CE(s)	Fisher Stat.	Prob.	Fisher Stat.	Prob.
None	147.4	0.0000	130.6	0.0000
At most 1	109.3	0.0000	96.28	0.0000
At most 2	105.6	0.0000	115.1	0.0000
At most 3	431.3	0.0000	431.3	0.0000

The Johansen Fisher Panel Cointegration Test was used to evaluate the long-term equilibrium relationships between chloride, conductivity, hardness and temperature. Trace and maximum eigenvalue statistics were combined to evaluate multiple cointegrating vectors (Table 4). The results strongly suggest cointegration between the variables, as the null hypothesis of no cointegration was rejected at all levels with p-values of 0.0000. This indicates a stable, long-term equilibrium relationship, meaning that changes in one variable affect the others over time. Preliminary tests, including stationarity tests, confirmed that the panel data variables are stationary, validating their use in further econometric modelling.

Table 5 – Discrete Threshold Regression of chloride (CL) as a dependent variable.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
CL (-4) < 5.599999 -- 262 obs.				
CONDUCTIVITY	0.076054	0.006079	12.51019	0.0000
TEMPERATURE	1.225970	0.226935	5.402296	0.0000
5.599999 <= CL (-4) < 7.3199999 -- 408 obs.				
CONDUCTIVITY	0.187795	0.008406	22.34006	0.0000
TEMPERATURE	-1.660537	0.250935	-6.617392	0.0000
7.3199999 <= CL (-4) < 13.949999 -- 465 obs.				
CONDUCTIVITY	0.295647	0.002596	113.9006	0.0000
TEMPERATURE	-4.577445	0.181765	-25.18338	0.0000
13.949999 <= CL (-4) < 22.339999 -- 253 obs.				
CONDUCTIVITY	0.281083	0.005435	51.71731	0.0000
TEMPERATURE	-4.334709	0.244777	-17.70881	0.0000
22.339999 <= CL (-4) -- 244 obs.				
CONDUCTIVITY	0.322294	0.002015	159.9697	0.0000
TEMPERATURE	-5.695948	0.202588	-28.11586	0.0000
Non-Threshold Variables				
HARDNESS	-0.168869	0.011382	-14.83609	0.0000
R-squared	0.965210	Mean dependent var		18.92897
Adjusted R-squared	0.964996	S.D. dependent var		45.50902
S.E. of regression	8.514473	Akaike info criterion		7.128129
Sum squared resid	117516.4	Schwarz criterion		7.164510
Log likelihood	-5805.554	Hannan-Quinn criterion		7.141625

Sample (adjusted): 8/30/2005 6/30/2020. Included observations: 1632 after adjustments. Variable chosen: CL (-4). Selection: Trimming 0.15, Max. thresholds 5, Sig. level 0.05.

Discrete threshold regression analysis for chloride (CL) and two-time points, CL (-3) and CL (-4), from 30 August 2005 to 30 June 2020, revealed a strong (R^2 = 0.965) and statistically significant (p<0.0001) association (Table 5). We used 1632 observations after adjustment and divided the data into five groups based on these time points whereby the EViews software at the end selected only 4 groups. A discrete threshold regression analysis was performed to examine the relationship between chloride concentration (CL) and the independent variables conductivity and temperature, with hardness serving as a non-threshold variable. Based on 1632 adjusted observations from August 2005 to June 2020, the EViews software identified significant thresholds for CL (-4) at 5.60, 7.32, 13.95 and 22.34. Conductivity had a consistently positive effect on CL, while temperature had a positive effect below 5.60 and a negative effect above this threshold. Hardness showed a consistently negative effect. The model showed a high explanatory power with an R-squared value of 0.965, which confirms the robustness of the results.

Table 6 – Discrete Threshold Regression of conductivity as a dependent variable.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
	CONDUCTIVITY (-2) < 253 -- 231 obs.			
CL	12.58846	0.409719	30.72459	0.0000
HARDNESS	0.857694	0.106579	8.047521	0.0000
TEMPERATURE	3.660592	1.546475	2.367056	0.0180
	253 <= CONDUCTIVITY (-2) < 277 -- 468 obs.			
CL	2.976138	0.064043	46.47065	0.0000
HARDNESS	1.112917	0.069755	15.95475	0.0000
TEMPERATURE	6.957445	1.098548	6.333309	0.0000
	277 <= CONDUCTIVITY (-2) < 300 -- 395 obs.			
CL	2.868930	0.065054	44.10066	0.0000
HARDNESS	1.034912	0.084580	12.23584	0.0000
TEMPERATURE	9.565714	1.358750	7.040084	0.0000
	300 <= CONDUCTIVITY (-2) < 330 -- 269 obs.			
CL	3.139500	0.029975	104.7387	0.0000
HARDNESS	0.760754	0.121149	6.279496	0.0000
TEMPERATURE	14.85469	2.012303	7.381934	0.0000
	330 <= CONDUCTIVITY (-2) -- 275 obs.			
CL	3.088912	0.030758	100.4273	0.0000
HARDNESS	0.159836	0.090387	1.768344	0.0772
TEMPERATURE	25.48100	1.525076	16.70802	0.0000
R-squared	0.955543	Mean dependent var		311.5806
Adjusted R-squared	0.955159	S.D. dependent var		148.6999
S.E. of regression	31.48819	Akaike info criterion		9.746217
Sum squared resid	1609214.	Schwarz criterion		9.795679
Log likelihood	-7967.152	Hannan-Quinn criterion		9.764562

Sample (adjusted): 7/12/2005 6/30/2020. Included observations: 1638 after adjustments. Variable chosen: CONDUCTIVITY (-2). Selection: Trimming 0.15, Max. thresholds 5, Sig. level 0.05.

Discussion

The analysis shows that the salinisation of the springs in the Bay of Bakar is mainly caused by the intrusion of warmer and saltier seawater and not by the rise in temperature itself. The most important indicators: chlorides, hardness, conductivity and temperature - show the intrusion of seawater into the springs.

Increased temperatures lead to increased evaporation, causing dissolved salts, including chlorides, to accumulate, resulting in higher chloride levels. This increase in chloride concentration directly increases the total ion content and thus the electrical conductivity of the water. In addition, higher temperatures accelerate the dissolution of carbonate minerals, which in turn contributes to increased water hardness. Therefore, the observed peaks in chloride content, especially during periods of high temperatures, correlate with an increase in both conductivity and hardness, indicating a complex interaction between seawater intrusion, temperature and mineral dissolution.

The study shows significant correlations between increasing heteroscedasticity of water temperature and the salinisation of springs in Bakar Bay. Reduced precipitation and increased seawater intrusion are the main causes for the increased chloride levels in these springs [6]. The Ghyben-Herzberg relationship explains how a lowering of the groundwater table due to lower precipitation favors the intrusion of saline seawater into freshwater aquifers. This process is exacerbated by the karstic geology of the region, which favors the dissolution of carbonates, further increasing the chloride concentrations and exacerbating further the evaporation process.

The panel data analysis confirmed significant positive correlations between chloride levels, electrical conductivity and water temperature. These models also showed non-linear relationships and threshold effects, indicating the variable influence of seawater intrusion on salinity. Higher conductivity values are generally associated with increased salinity due to the presence of dissolved salts. This study emphasizes the importance of understanding the dynamic reinforcing and interactions between temperature, seawater intrusion and freshwater quality in coastal karst areas.

Conclusion

A significant portion of Croatia's drinking groundwater is stored in karst aquifers. The rise in chloride concentration in Bakar Bay Springs is due to seawater intrusion according to the Ghyben-Herzberg relationship. Increased temperatures at the springs accelerate dissolution of carbonates, and higher evaporation rates concentrate the dissolved salts accelerating furthermore the effect. These factors highlight the sensitivity of karst regions to temperature changes and the importance of considering geological factors and evaporation rates when assessing climate change impacts on coastal water quality.

Acknowledgments

This work was supported by the University of Rijeka under the project numbers: uniri-iskusni-prirod-23-177; ZIP-UNIRI-2023-7, and uniri-iskusni-drustv-23-163.

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ASSESSMENT OF THE QUALITY OF MARINE BATHING WATERS USING DIFFERENT METHODS OF PERCENTILE CALCULATION

Diana Mance, Zrinka Vrček, Arijana Cenov, Marin Glad, Davor Mance, Darija Vukić Lušić

Abstract: *Escherichia coli* (*E. coli*) and intestinal enterococci (ENT) are the indicator bacteria used to test the microbiological quality of bathing water. In Croatia, the quality of bathing water is assessed by parametric method i.e. on the basis of the 90th and 95th percentile values which are calculated using the corresponding arithmetic mean and standard deviation of the logarithmic bacterial concentrations. There are also non-parametric methods for determining the value of a particular percentile, and one of them is the so-called Hazen method. In this work, we study how the different methods of percentile calculation affect the assessment of coastal bathing water quality. We have chosen a "problematic" location with frequently elevated bacterial concentrations as a test site.

The results show that in the case of *E. coli*, the 95th percentile values calculated using the Hazen method are significantly lower than those calculated using the parametric method (Wilcoxon rank test, $p < 0.05$), while for ENT there was no statistically significant difference. For case of annual assessment, the difference in coastal bathing water quality was statistically significant for both ENT and *E. coli* (McNemar test, $p=0.004$ and $p=0.02$ respectively). In the final classification, the difference in coastal bathing waters quality was statistically significant only in the case of *E. coli* (McNemar test, $p=0.025$).

Keywords: microbiology, bathing water quality, statistical methods, Hazen percentile method

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Diana Mance, Zrinka Vrček, Arijana Cenov, Marin Glad, Davor Mance, Darija Vukić Lušić, *Assessment of the quality of marine bathing waters using different methods of percentile calculation*, pp. 946-955, DOI: 10.36253/979-12-215-0556-6.82

Introduction

The quality of bathing water is not only crucial for public health but also for the growth of sustainable tourism. It is influenced by both natural and anthropogenic elements [1-3]. The main objectives of the European Union's Bathing Water Directive 2006/7/EC, which regulates the management and quality of bathing water, are to preserve and protect the environment, as well as to improve quality, and protect human health [4]. *Escherichia coli* (*E. coli*) and intestinal enterococci (ENT) are the two indicators of faecal pollution used to routinely test the microbiological quality of bathing waters.

In Croatia, the quality of coastal bathing waters has been systematically monitored for more than 30 years. During this time, numerous parameters of the monitoring program have changed: regulations, microbiological criteria and test methods, limit values for individual categories of water quality, but also statistical procedures and methods of data processing. The quality of bathing waters is currently assessed on the basis of the values of the 90th and 95th percentiles[1] [5]. The procedure involves calculating logarithms of the bacteria concentrations, and the determination of the corresponding arithmetic mean and the standard deviation. Based on the determined values of the 95th and 90th percentiles and predefined intervals, the coastal bathing water quality is classified as excellent, good, sufficient or poor [3, 5].

The method described for determining the value of a particular percentile is also known as the parametric method, as the arithmetic mean and the standard deviation are used for the calculation. These are the measures of central tendency and variability for data sets that are distributed according to a normal distribution. Since bacterial data are almost never normally distributed, the question arose as to whether this method is suitable for analysing this type of data. There are several non-parametric statistical techniques (statistical methods that do not assume a normal distribution of the data) to determine the value of a particular percentile, and each has advantages and disadvantages of its own. The New Zealand Ministry of the Environment, for example, uses the Hazen method to determine the value of a particular percentile [6]. In this paper, we have compared the 90th and 95th percentile values, as well as the classification of coastal bathing water quality, based on calculations using the parametric method and the Hazen method. Since the Hazen method is ultimately intended to replace the parametric method, this type of comparison is necessary to determine whether possible changes in the water classification are due to actual changes in water quality or to a change in the method used to calculate the percentiles.

Materials and Methods

In Primorje-Gorski Kotar County (Croatia), the quality of the sea is regularly tested at approximately 300 locations during the bathing season. In most cases, the

[1] Percentiles are generally described as the proportion of values in a set of data that fall below a given number. The 90th and 95th percentile values therefore indicate the lower limits below which 90 % and 95 %, respectively, of the total data in a given set can be found.

sea proved to be of excellent quality [2]. Sites with the highest water quality are not interesting for our analysis, so we have chosen a "problematic" site where microbiological contamination is not uncommon. The data were obtained for samples collected during the bathing season from 2009 to 2022. The seawater for recreation is sampled on average every 14 days at a specific location during the bathing season. Therefore, in most cases (11 times, 78.6 %) there were 10 analysed samples per year at a given location. The maximal number of samples per year was 13. A total of 146 samples were analysed for each of the bacteria of interest. Both *E. coli* and ENT were cultured according to the standardized methods and analysed using the membrane filtration technique [7, 8]. The results (bacteria concentrations) are expressed in the number of colony-forming units in 100 mL of water (CFU/100 mL).

In the parametric method for determining the values of the percentiles, we used the procedure described in the regulation [5]. Calculation of the logarithm of the concentration value[2], calculation of the corresponding arithmetic mean (μ) and standard deviation (σ), and finally determination of the value of the 90th percentile (1), and the 95th percentile (2):

$$90^{th}\ \text{percentile}=\text{antilog}(\mu+1.282\cdot\sigma) \tag{1}$$

$$95^{th}\ \text{percentile}=\text{antilog}(\mu+1.65\cdot\sigma) \tag{2}$$

We used an interactive calculator to calculate percentile values based on the Hazen method [9]. The percentile calculations were carried out at the end of each bathing season (annual assessment) and on the basis of data from the current and the three previous bathing seasons (final assessment). The classification of the coastal bathing water is according to Table 1.

Table 1 – Standards for the assessment of coastal bathing water quality according to national regulation [5].

	Bathing water quality			
Indicator (CFU/100 mL)	Excellent	Good	Sufficient	Poor
intestinal enterococci	≤ 100*	≤ 200*	≤ 185**	> 185**
Escherichia coli	≤ 150*	≤ 300*	≤ 300**	> 300**

*based on the value of 95th percentile
**based on the value of 90th percentile

The statistical software jamovi [10] and RStudio [11] were used for the statistical analysis, and the results were interpreted at a significance level of 5%. The Shapiro-Wilk test was used to test the normality of the distribution of the bacterial

[2] If the bacterial concentration is 0 CFU/100 mL, the concentration is regarded as the detection limit, in our case, 3 CFU/100 mL.

concentration data. As it was found that the data were not normally distributed, the median was used as a measure of central tendency and the interquartile range (IQR) as a measure of variability. The Mann-Whitney U test was used to compare the mean values of ENT and *E. coli* concentrations. The Wilcoxon rank sum test for paired samples was used to compare the mean percentile values calculated by the parametric and Hazen methods. Coastal bathing water classifications were compared with the McNemar test.

Results

The median value of the ENT concentration is 18 CFU/100 mL, with a minimum value of 3 CFU/100 mL (lower detection limit) and a maximum value of 290 CFU/100 mL. For *E. coli*, the median is 22 CFU/100 mL, and the corresponding minimum and maximum values are 3 CFU/100 mL and 520 CFU/100 mL. The results of the Mann-Whitney U-test (p=0.02; Table 2) show that the values for *E. coli* are significantly higher than the concentration values for ENT.

Table 2 – Descriptive statistics for the concentrations (in CFU/100 mL) of intestinal enterococci and *Escherichia coli*. The significance of the difference between the mean bacterial concentrations was tested with the Mann-Whitney U test. IQR – interquartile range.

Microbiological parameter	median	IQR	Minimum	Maximum	p-value (Mann-Whitney U test)
enterococci	18	39.8	3	290	0.02*
E. coli	22	93.5	3	520	

*statistically significant

Table 3 – Intestinal enterococci: Median values of the 90th and 95th percentiles for annual and final (current season and three previous seasons) assessment, calculated using parametric and Hazen methods. The significance of the difference between the medians was tested using the Wilcoxon rank test for paired samples. IQR – interquartile range.

Percentile	Assessment	Method	Median (CFU/ 100 mL)	IQR (CFU/ 100 mL)	p-value (Wilcoxon rank test)
90th	annual	parametric	85	47.75	0.263
		Hazen	82.5	41.25	
	final	parametric	78	24	0.197
		Hazen	80	4	
95th	annual	parametric	125.5	84.5	0.055
		Hazen	86	65	
	final	parametric	126	33.5	0.197
		Hazen	122	44	

The comparison of the values of the 90th and 95th percentiles for the annual and final assessment shows that in the case of ENT there is no statistically significant difference between the values determined using the parametric and Hazen methods (Table 3). In the case of *E. coli*, the difference proved to be significant, but only in the case of the 95th percentile value (Table 4).

Table 4 – *Escherichia coli*: Median values of the 90th and 95th percentiles for annual and final (current season and three previous seasons) assessment, calculated using parametric and Hazen methods. The significance of the difference between the medians was tested using the Wilcoxon rank test for paired samples. IQR – interquartile range.

Percentile	Assessment	Method	Median (CFU/ 100 mL)	IQR (CFU/ 100 mL)	p-value (Wilcoxon rank test)
90th	annual	parametric	195	71	0.572
		Hazen	156	118.3	
	final	parametric	198	44	0.365
		Hazen	185	53.5	
95th	annual	parametric	345	149.3	0.03*
		Hazen	186	132	
	final	parametric	345	63	0.005*
		Hazen	260	83	

*statistically significant

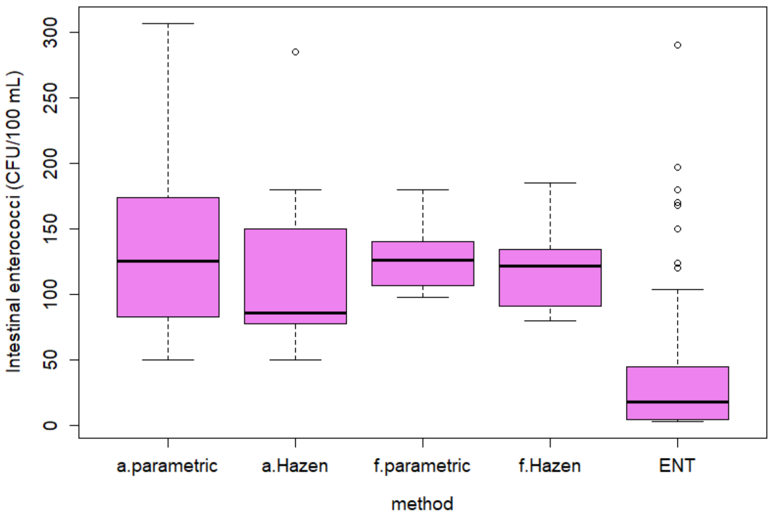

Figure 1 – Intestinal enterococci 95th percentile for: a.parametric – annual assessment calculated using the parametric method, a.Hazen – annual assessment calculated using the Hazen method, f.parametic – final assessment calculated using the parametric method and s.Hazen – final assessment calculated using the Hazen method. ENT – the intestinal enterococci concentration is given for comparison.

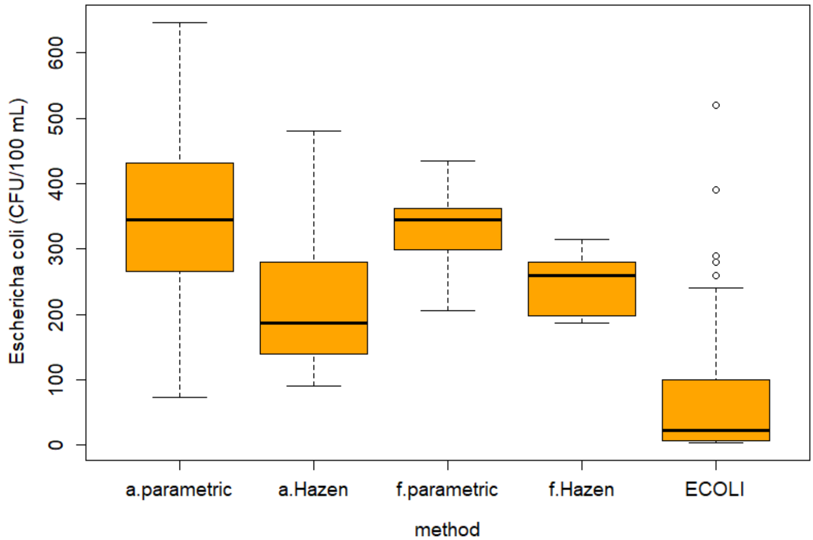

Figure 2 – *Escherichia coli* 95th percentile for: a.parametric – annual assessment calculated using the parametric method, a.Hazen – annual assessment calculated using the Hazen method, f.parametic – final assessment calculated using the parametric method and s.Hazen – final assessment calculated using the Hazen method. ECOLI – the *Escherichia coli* concentration is given for comparison.

Figures 1 and 2 show comparisons of the 95th percentile values calculated using the parametric and Hazen methods for ENT and E. coli, respectively

According to Table 1, we determined the coastal bathing water quality for a annual and final assessment based on the concentration of ENT (Figure 3) and *E. coli* (Figure 4). For further statistical analysis and due to the small amount of data, we have combined the categories "excellent" and "good" in the "higher" category and the categories "sufficient" and "poor" in the "lower" category. In the annual classification, the difference in classification proved to be statistically significant both in the case of ENT (McNemar test, p=0.004, Figure 5) and in the case of *E. coli* (McNemar test, p=0.02, Figure 6). In the final classification, the difference was statistically significant only for *E. coli* (McNemar test, p=0.025), where the quality of the seawater was rated better than the quality determined by the parametric method in 45.5 % of cases.

Intestinal enterococci / year	annual assessment		final assessment	
	parametric	Hazen	parametric	Hazen
2009	S	G		
2010	E	E		
2011	E	G		
2012	G	G	G	G
2013	G	E	G	G
2014	E	E	E	G
2015	G	E	G	G
2016	E	E	G	E
2017	G	G	G	E
2018	G	E	G	E
2019	S	G	G	G
2020	E	E	G	G
2021	G	E	G	G
2022	S	P	G	G

Figure 3 – Coastal bathing water quality (annual and final assessment) based on the values of the 90th and 95th percentiles of intestinal enterococci concentrations calculated using the parametric and Hazen methods. E- Excellent; G – Good; S – Sufficient; P – Poor according to the Table 1.

Escherichia coli /year	annual assessment		final assessment	
	parametric	Hazen	parametric	Hazen
2009	E	E		
2010	S	G		
2011	E	E		
2012	S	G	G	G
2013	S	G	G	G
2014	S	E	G	G
2015	S	G	S	G
2016	S	G	S	G
2017	G	S	S	G
2018	G	G	S	G
2019	P	P	S	S
2020	E	G	S	S
2021	S	G	S	S
2022	S	G	S	G

Figure 4 – Coastal bathing water quality (annual and final assessment) based on the values of the 90th and 95th percentiles of *Escherichia coli* concentrations calculated using the parametric and Hazen methods. E- Excellent; G – Good; S – Sufficient; P – Poor according to the Table 1.

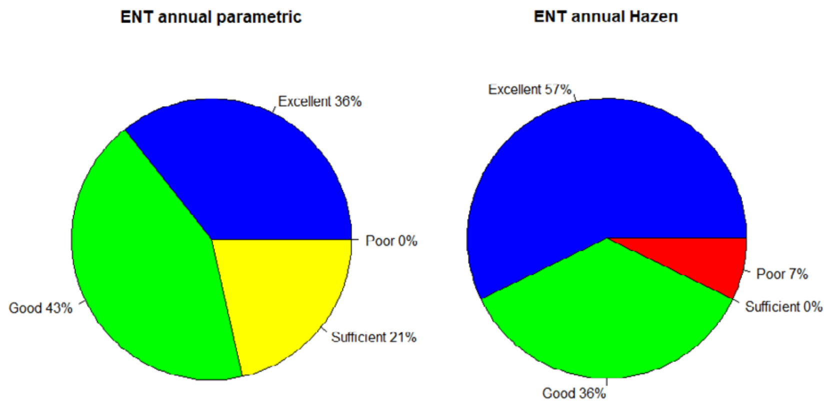

Figure 5 – Changes in coastal bathing water quality (annual assessment based on the concentration of intestinal enterococci - ENT) as a result of different methods for calculating the 90th and 95th percentiles: parametric method (left) and Hazen method (right).

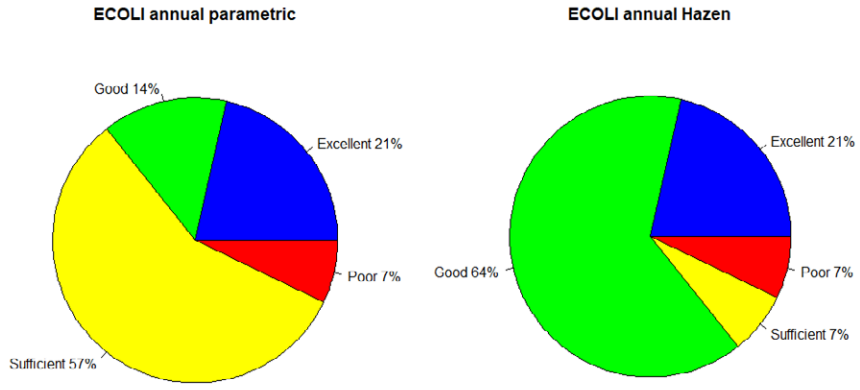

Figure 6 – Changes in coastal bathing water quality (annual assessment based on the concentration of *Escherichia coli* - ECOLI) as a result of different methods for calculating the 90th and 95th percentiles: parametric method (left) and Hazen method (right).

Discussion

In Croatia a programme for the coastal bathing water quality monitoring has been in place for more than three decades, providing us with a long continuity of data. In addition to real changes in the environment, changes in the methodology for analysing microbiological indicators, changes in assessment criteria and statistical data processing also have an impact on the classification of beaches. These factors must be taken into account when assessing the state of the environment and monitoring long-term trends.

The data on ENT and *E. coli* concentrations were analysed over 14 consecutive bathing seasons at a site with frequently elevated levels of these indicator bacteria. It was found that the *E. coli* concentrations were significantly higher than the ENT concentrations.

As the 90th and 95th percentile values are used to determine the quality of coastal bathing waters, the values calculated using the parametric (standard) method and the Hazen method were compared. It turned out that these values are significantly lower in the case of the 95th percentile values of *E. coli* calculated with the Hazen method.

In the case of coastal bathing water quality, we see that the Hazen method has a significantly higher number of results with better water quality compared to the parametric method.

From a public health perspective, the underestimation of bathing water quality is a minor problem, considering that the main objective of water quality monitoring is to protect public health. On the other hand, it is important not to overestimate the risk of transmission of infectious diseases when using recreational waters, as the implementation of remedial measures can lead to significant economic damage.

Conclusion

Parametric statistical methods are considered to be more rigorous and intuitive statistical methods compared to non-parametric methods. A prerequisite for the application of parametric methods is the normal distribution of the analysed data. In the case of bacteriological water pollution, this requirement is usually not met. Therefore, it is expected that the non-parametric (Hazen) method may become the new standard for the assessment of coastal bathing waters quality.

By comparing the results obtained with the parametric and Hazen methods, we aim to determine whether a change of method affects the final results of the coastal bathing water quality classification. Our results show that the change of method significantly affects the results of the quality assessment. In fact, we can expect the Hazen method to provide data indicating higher water quality.

The results reported in this article should be interpreted with caution as only one site was studied. Including a larger number of sites in this type of study would lead to more reliable results.

Acknowledgements

This work was funded by the UNIRI projects uniri-iskusni-prirod-23-177; uniri-iskusni-drustv-23-163 and uniri-iskusni-biomed-23-245 (https://www.croris.hr/projekti/projekt/10322)

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RENEWABLE ENERGY AND SARDINIAN COASTAL AREAS: MARKET AND ENVIRONMENTAL ISSUES

Martino Marini, Andrea Sulis

Abstract: The role of renewable energy sources is changing as they are set to replace fossil sources to accomplish the energy requirements in the next future. The direction is set, and energy planners specified quite close dates when to achieve important shares in energy production portfolio by renewables. After considering the meaning of energy communities in the development of renewable sources in a bottom-up perspective, the prediction of vertical axis wind turbines performance is presented to focus the attention on this configuration which is not full commercial TLR as well. The wave energy converters are another example of devices to exploit renewable sources which are gaining a special interest. An application concerning Sardinian coastal areas is presented and some results concerning its energy performance is discussed.

Keywords: wave energy converter, wind turbine, nearshore areas, energy community

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Martino Marini, Andrea Sulis, *Renewable energy and Sardinian coastal areas: market and environmental issues*, pp. 956-966, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.83

Introduction

Electricity generation from wind energy is clean, to the extent that it neither alters chemical composition of the environment by entering greenhouse gases nor issues noxious emissions that pollute the air as fossil fuels routinely do. This applies equally to other renewable sources, from the basic sun to the wave potential still under observation, which do not deplete the environment of essential elements to secure natural habitat and ecosystems.

The global power production from renewables is expected to reach 13 % in 2035 by global energy planners. However renewable energy sources still have a potential to be developed as in various areas they are not easily accepted for their environmental issues. To this respect coastal areas of an island like Sardinia are characterized by a very high environmental value with economic and commercial implications. Nevertheless, they are endowed with significant renewable resources concerning the sun, the wind, and the waves.

The exploitation of these energy sources must confront technical and landscape constraints. Namely quantifying the wave power resource and designing a device for its exploitation is still a challenge while that is not the case of the wind with its turbines or the sun with its PV panels, both using technologies at commercial TRL. In addition, the challenge when using wind and sea for electricity supply is their unsteady electricity production rate, which is not easy to adapt to the varying electricity demand. Previous studies (e.g. [1]) confirm that a mix of flexibility resources is needed to manage variability across all timescales and seasons. Turbines and panels require seasonal flexibility services, which can be provided from Wave Energy Converter (WEC).

The fulfilment of a growing share of electricity needs with renewable sources is following a complex path where, however, fairly clear trends can be identified. On the one hand generating assets based on large wind turbines and on arrays of PV panels that cover very large areas follow the logic of comparatively concentrated energy production to be fed into the grid, with actors and stakeholders external with respect to the territory. In a free market scenario, albeit in compliance with national and European regulations, the profit motive is associated with the use of increasingly larger machines, compatible with the objective of promoting renewable sources. On the other hand, the distributed generation, linked to the territory needs, keeps being one of the characteristics of renewable sources and this solution has recently been encouraged with specific directives.

The EU Renewable Energy Directive 2018/2001 (RED II) has unlocked the participation of local citizens and authorities in collective renewable energy projects through the concept of Renewable Energy Communities (REC). This Directive establishes a common framework for the promotion of energy from renewable sources. It sets a target for the overall share of energy from renewable sources in the gross final consumption of energy of the Energy Community in 2030, in line with Regulation (EU) 2018/1999. Energy communities are open and voluntary and combine non-commercial purposes with community environmental and social objectives [2].

Three directives describe the key elements of two types of Energy Communities, namely Renewable Energy Community and Citizen Energy

Community. Both the gas market directive and the electricity market directive fall under the category of city energy communities. A clarification and some detail can be helpful for both.

Renewable energy community is a legal person: (a) which, in accordance with applicable national law, is based on open and voluntary participation, is autonomous and is effectively controlled by shareholders or members who are located in proximity to renewable energy projects owned and developed by that legal entity ; (b) whose shareholders or members are natural persons, SMEs (small and medium-sized enterprises) or local authorities, including municipalities; (c) the primary purpose of which is to provide environmental, economic or social benefits to the community for its shareholders or members or to the local areas in which it operates, rather than financial profits.

Citizen Energy Community is a legal person who: (a) is based on voluntary and open participation and is effectively controlled by members or shareholders who are natural persons, local authorities, including municipalities, or small businesses; (b) has as its primary purpose to provide environmental, economic or social community benefits to its members or shareholders or to the local areas in which it operates rather than to generate financial profits; (c) may engage in generation, including from renewable sources, distribution, supply, consumption, aggregation, energy storage, energy efficiency services or electric vehicle charging services or provide other energy services to its members or shareholders.

In a broad sense, energy communities are contiguous processes of both energy transition and social innovation. As decentralized and renewable energy projects, they can promote sustainable energy production and consumption practices. As consumer-empowerment and community-driven initiatives, energy communities can play a key role for social innovation as they reflect a fundamental shift in consumer behavior.

Italy is considered a laggard country since it presents significant shortcomings and delays in policy management and ECs setup and diffusion in its territory. The following list presents the principal regulations in the Italian regulatory framework regarding energy communities. ”Milleproroghe” Decree 30 December 2019 n.162 (converted into law on 28 February 2020 n.8) legally defines the energy communities through the art. 42bis, which specifies the two possible schemes of energy community feasible in Italy: collective self-consumption and Renewable Energy Communities (REC). Legislative Decree 8 November 2021 n.199 establishes that the REC participants regulate their relationship through a private law contract, which defines the rights and obligations of the individuals.

«Milleproroghe» considers RED II principles and defines the specific characteristics of the two schemes. It defines the scale at which the REC can operate since communities must be connected to the same medium voltage/low voltage (MV/LV) substation with the maximum incentivized power for each renewable energy system fixed at 200 kWp. Besides, the users can share energy instantaneously and use a storage system. Legislative Decree 2021 n.199 transposes the RED II Directive and allows incentives on the “shared energy”, evaluated as the net difference between the electricity fed into the grid and the energy taken from the grid. These incentives equal 100 €/MWh for self-consumption and 110 €/MWh for REC.

Among the environmental advantages of energy communities the spread of renewables, at present especially photovoltaic, but this does not preclude the use of other sources technologies, such as wind, or waves together with batteries instead of fossil fuels. This implies a decrease in harmful emissions of the gases responsible for the greenhouse effect, especially carbon dioxide. Furthermore, energy dissipation in network losses is avoided thanks to less distance to cover and direct self-consumption by members.

As for social benefits, the creation of a community attentive to environmental sustainability promotes the diffusion of models of inclusion and collaboration capable of generating benefits for the territory and for the people who live there.

Materials and Methods

This paper presents preliminary results of numerical application to a WAB located in the nearshore area along the Western Sardinian coast. This energy source can be profitably matched with wind, as they share the origin to a good extent. Modeling of a small size wind turbine for the same location is considered, focusing on configurations of wind turbines which have been intensively studied but are not widespread at present as Vertical Axis Wind Turbines. The wave and wind systems can be effectively proposed by a combined device in the coastal context due to their limited visual impact especially for small scale facilities. The energy community which contributes to increasing public acceptance of renewable energy projects and make it easier to attract private investments in the clean energy transition, is in the background.

Wind energy

Wind turbines are a convenient device to capture and convert kinetic energy of the atmosphere into mechanical and, most commonly, electrical energy. Wind turbines are classified in two major categories based on rotational axis: horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs) or cross-flow turbines.

Wind turbines currently in operation are mostly HAWTs, because they have evolved to a mature and competitive system because of extensive research and commercialization. Indeed, VAWTs are comparable to HAWTs from various angles altogether. Further, in certain areas of operation a VAWT appears preferable to a HAWT, such as in a gusty urban environment or in locations with strict space constraints. The arguments used to derive the Betz limit for a HAWT do not apply directly to a VAWT, as recent analyses using an evolutionary algorithm have shown. The optimal pitch curve can yield power output from a VAWT that is approximately 6 % higher than the Betz limit, due to its aerodynamic behavior [3].

The aerodynamic performance of a straight bladed vertical axis turbine is predicted by different models, ranging from those based on a 1D approach and the actuator disk theory to those which resort to CFD resources [4]. Hereafter the characteristic curves of a set of vertical axis wind turbines with straight blades, obtained by the free wake vortex model, are shown (Figure 1). The turbines are all equipped with three blades rotating at a distance R from the hub, but the chord length c constant along the blade span, is changing (Figure 2). The NACA 0012 airfoil has been adopted to design the blade sections, and its experimental data were integral part of the semi empirical modeling. TSR is the peripheral speed (ωR) referred to wind speed v, while C_P is the turbine power referred to the upstream wind power 0.5 $\rho A v^3$where A=2RH is the swept area being H the blade height.

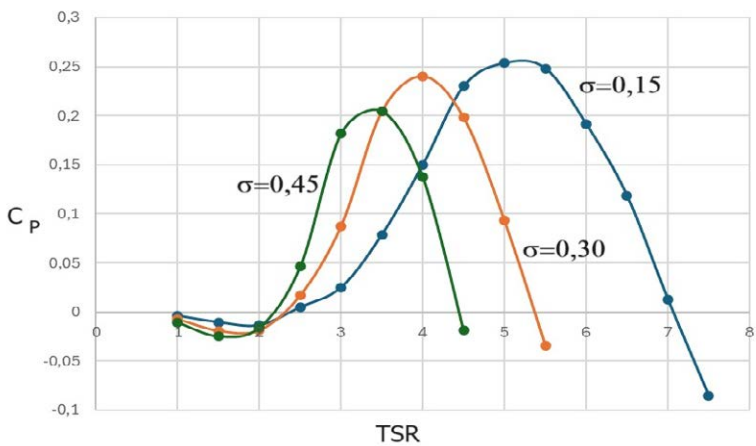

Figure 1 – Power coefficient (*CP*) vs. tip speed ratio (TSR) for 3 bladed VAWTs for different solidity values (σ=Nc/R).

These calculations are addressed to vertical axis wind turbine design, while more accurate models are used in wind turbine analysis. Helical Darrieus turbine can be calculated following the same approach, they account for a smoother operation at the cost of a more complicated setup.

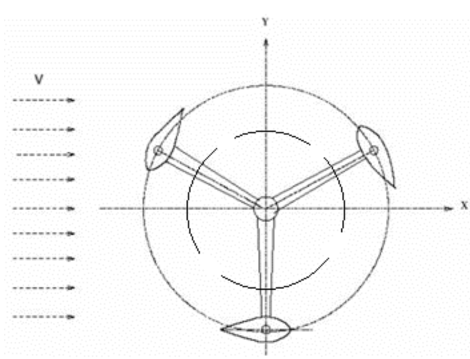

Figure 2 – Three bladed VAWT schematic.

The annual production of energy depends on the wind potential which is quite plentiful in Sardinian coastal areas as evidenced by measured data.

Wave energy

Wave energy is a renewable and pollution-free energy source that could have the potentiality to for a substantial contribution in the EU electricity energy market. The EU industry is the global leader for developing ocean energy technologies, mainly wave and tidal. Ocean energy technologies are relatively stable and predictable and can complement fixed and floating offshore wind. The EU Communication (see [5]) proposed an ocean energy strategy where different technologies should suit different sea basins. The variety and complementarity of European sea basins create a unique worldwide position, but different technologies development and commercial levels have become too large across European basins. While the North Sea is currently the world's leading region for deployed capacity and expertise in waves, the good potential for wave energy in the Mediterranean Sea is far to be properly used and wave technologies are still pilot and in demonstration phase. Recently, extensive and accurate estimates of wave energy along the Mediterranean coasts have been provided by many authors. Estimates of the available mean power (P_m) in kW/m and the related potential energy production suggests that an energy hotspot is located in the Western coasts of Sardinia (Italy) (see [6]) with P_m = 11.4 kW/m (Figure 3).

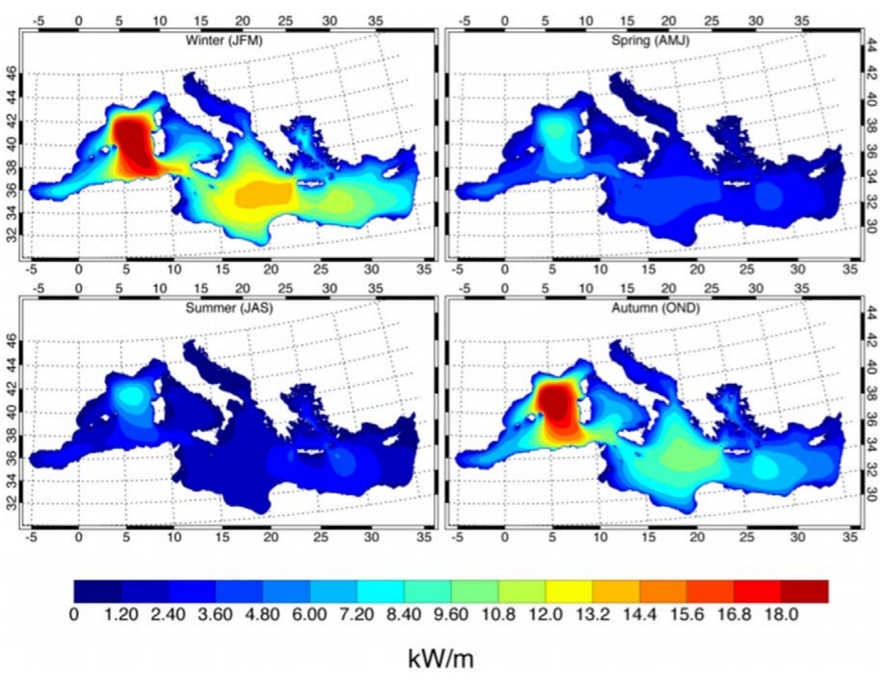

Figure 3 – Seasonal wave power in the Mediterranean Sea (adapted from [6]).

The main aim of the proposed research is to demonstrate that a proper selection and customization of a Wave Energy Converters (WEC) operating in an EU oceanic basin with greater energy potential could produce profitable power output in the Western coasts of Sardinia. Specifically, the assessment of the energy potential in the hotspot located offshore of the city of Alghero and the comparisons between the simulated WEC energy productivities in Alghero and in the North Sea will be presented. The content of the presentation will be of evident interest for Sardinian communities that want to invest in this field and thus need to optimize the WEC for specific wave climate to reach the level of commercial maturity. The seasonal trends of wind, solar and wave resource are shown in figure 4, where the demand variation is presented as well [7].

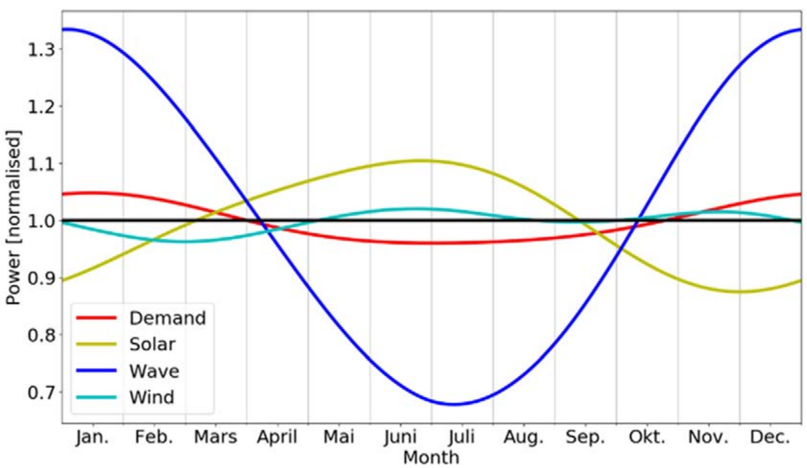

Figure 4 – Seasonal power fluctuations.

Results and discussion

The essential features in which a WEC should excel in order to show long-term economic potential include the survivability (reliable mooring system and preferably a passive safety system that can effectively reduce extreme loads), reliability and maintainability (easy access and inspection of the most essential parts of the WEC), overall power performance (efficient wave energy absorbing technology and PTO), scalability (capable of further enlarging its dimensions to improve its Levelised Cost of Energy - LCoE) and high environmental benefit (expected to have a great environmental benefit and a minimal environmental footprint). Floating Wave Activating Bodies (WAB) in offshore and nearshore areas have had successful results in technology development level (e.g., AquaBuoy, IPS Buoy, FO3, PowerBuoy, WavePiston, Pelamis).

The purpose of the study is to demonstrate a full-scale Wavepiston system with electricity conversion to verify the potential strengths and limitations for commercial projects.

The main properties of wave climate are an annual mean significant wave heigh of 1.2 m (and a peak period of 6.7 s) with a 18 year return time wave height of 9.2 m. The predominant wave direction is from North-West. According to the analysis at Mediterranean scale of Figure 3, here P_m is estimated as equal to 10.5 kW/m.

Long term changes in sea states are relevant to climate research and coastal applications along the coasts of Sardinia Island, located in West Mediterranean Sea (WMS). Recent sea state high-quality data records (satellite altimetry dataset from ESA, and reanalysis and hindcast products from ECMWF) show temporal trends in annual mean significant wave height (Hs) over 1992 – 2018 from a 2° x 2° grid in WMS (see [8]).

In enclosed basins as a gulf, the waves have characteristics rather different than in large environment. This is mainly due to their local generation, and they depend more on the quality of winds (coastal orography) and transformation (bathymetry) [9]. Sulis et al. [10] presented a 20-year wave dataset (altimeters on board of the ERS-1/2 and TOPEX/Poseidon satellites, and the operational wind and wave results from ECMWF) from which statistics have been derived in the grid point of coordinates 9.5°E; 39.0°N located at the mouth of the Gulf of Cagliari about 8 km south of the Sardinia coast (Figure 5).

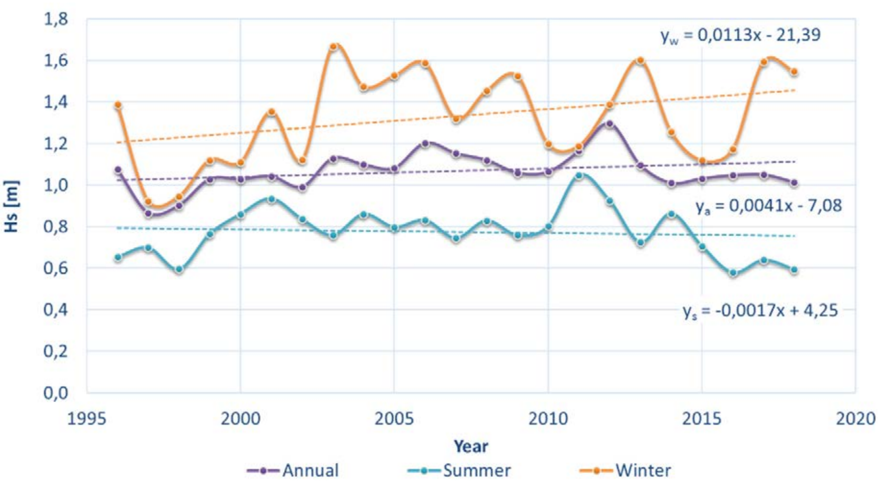

Figure 5 – Seasonal and annual trends of maximum wave heights in Western Sardinia coasts, offshore Alghero

Here temporal trends are estimated using simple linear regression over 5-year moving averages of annual maximum Hs [10]. Analysis shows a strong positive trend over the last decade along the ordinary least square equation (R^2 = 0.92), being the rate equal to + 4 mm/yr. Increases in maximum annual heights have been in accordance with mean condition.

The full-scale demonstration system consisted of a single Wavepiston WEC (the string) with up to 32 energy collectors (length 400 m, width 9 m) and a turbine generator on the PLOCAN platform for conversion to electricity. Multiple energy collectors are coupled on a string with each string corresponding to a wave energy converter. Each energy collector has a sail, which is moved back and forth by the passing waves (Figure 6).

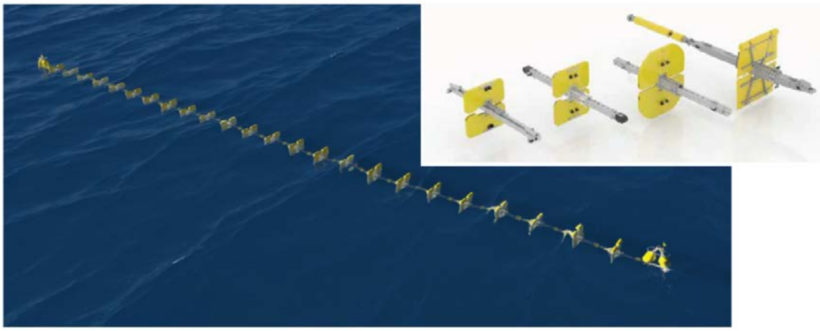

Figure 6 – Wavepiston WEC: string and details of different energy collectors [8].

The system is expected to have a peak effect of 200 kW, being able to produce 400 MWh per year with a fairly (equal to the electricity consumption of approximately 150 standard households), as shown in Figure 7 histogram.

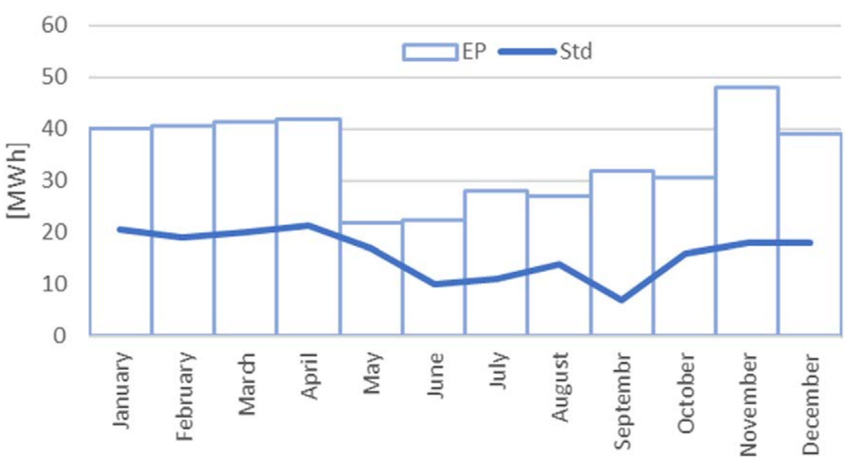

Figure 7 – Monthly average farm electricity production EP (MWh) and its standard variation Std of the simulation time [adapted from [8]).

According to other study on the implications of wave trends for wave energy exploitation (see [11]), the Alghero offshore area will experience a significant increase in energy production in future scenarios as defined by trends for annual mean values of wave height. In this research, we found a convergence in the trends for annual mean and maximum of wave height, and in a preliminary way we assessed a future relative variation in the annual energy production approximately equal to 8 % to 2050.

Conclusion

The wind and wave energy can be treated as an asset for Sardinian coastal areas. They can be profitably proposed in a combined device into the specific context due to their limited visual impact especially for small scale systems. The energy community which contributes to increasing public acceptance of renewable energy projects and make it easier to attract private investments in the clean energy transition, is in the background.

Some results about energy conversion systems have been obtained taking into accounts recent developments.

From the model application to Alghero climate conditions, it appears that the main strengths of the RES from wave motion can be summarized as follows:

- Final Development and Qualification Level (TRL) for fairly energetic wave climates (> 40 kW/m).
- Excellent synergies with other energy sources (e.g., offshore wind);
- Very low impact and high environmental sustainability.
- Good efficiency, lifetime and performance.
- Presence in Italy of excellence in research in the sector and in industrial development.

Then, the main obstacles to the exploitation of wave motion RES are:

- Need to customize devices for low-energy wave climates (5 – 15 kW/m);
- High initial investment of the systems now appearing on the market.
- Presence at national and regional level of complex regulations for the permitting and installation process of devices.

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μ-NAUTILUS, AN AUTONOMOUS LIGHTWEIGHT PROFILER WITH DEPTH CONTROL AND CONFIGURABLE SAMPLING TIME

Isabel P. Morales-Aragón, Roque Torres-Sánchez, Javier Gilabert, Fulgencio Soto-Valles

Abstract: Coastal lagoons, such as Mar Menor, hold significant ecological importance but are vulnerable to environmental disruptions from resource exploitation. Continuous monitoring is crucial for understanding critical situations and assessing recovery efforts. Manual sampling, as used in Mar Menor, is costly and yields limited results. Therefore, demand exists for automatic methods to enhance data collection and reduce operational tasks. This paper presents the design of a compact autonomous submersible profiler, μ-Nautilus, building upon the previous s-Nautilus model. It weighs 11 kg, which is half the weight of its predecessor. μ-Nautilus aims to stop at a configurable depth with less than 20 cm depth error using a single 750 cm^3 ballast tank for control. Cascade control is employed, and satisfactory depth control (±15 cm error) is obtained during tests at sea. μ-Nautilus is powered by batteries with a capacity of 12.8 Ah and 11.1 V to run the ballast tank and 16.75 Ah and 3.6 V for the rest of the electronics. It can operate autonomously for 48 days performing cycles every 6 hours, suitable for the cleaning frequency needed due to fouling in Mar Menor.

Keywords: profiler, sensor platform, WSN, depth control, Mar Menor

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Isabel P. Morales-Aragón, Roque Torres-Sánchez, Javier Gilabert, Fulgencio Soto-Valles, *μ-Nautilus, an autonomous lightweight profiler with depth control and configurable sampling time*, pp. 967-976, DOI: 10.36253/979-12-215-0556-6.84

Introduction

The monitoring of marine environments is currently experiencing a period of significant growth, driven by the need to better understand the behavior of these ecosystems and address the environmental challenges they face. A prominent case is the Mar Menor, the largest hypersaline coastal lagoon in Europe where various agricultural, economic, and touristic activities converge.

The Mar Menor provides numerous ecosystem services to society, including significant fisheries, extensive tourist and recreational activities on its beaches, and a variety of nautical activities supported by numerous marinas and extensive urban developments. However, the basin that feeds into the Mar Menor hosts one of most technologically advanced agricultural sectors of Europe, characterized by intensive cultivation and high economic yields. Over the years, this intensive agriculture has resulted in an excess of nitrogen in the aquifer. Consequently, during the rainiest seasons, such as in recent years, there has been an increase in the discharge of groundwater laden with nitrates, leading to severe eutrophication episodes like the one in 2016 and subsequent events such as the mass fish mortality incidents in 2019 [8] and 2021, each resulting in over five tons of dead organisms, significantly impacting the biodiversity of the lagoon. These environmental crises have led to declines in fisheries [10] and considerable depreciation in housing prices in the area [4], [5]. However, spurred by citizen mobilization, the Mar Menor has achieved a significant milestone in Europe by being granted rights of personhood, recognizing the lagoon's right to exist as an ecosystem and evolve naturally, as well as its rights to protection, conservation, maintenance, and restoration [9].

To address the challenges of protection and restoration the importance of continuous and detailed monitoring of the Mar Menor lagoon has been recognized. In the Mar Menor monitoring programs, data collection has been carried out manually at different points in the lagoon on a weekly basis [1]. However, this approach has limitations in terms of human and economic resources. In addition, the low sampling frequency makes it difficult to draw clear conclusions and to develop predictive models for the hydrodynamic behavior of the lagoon.

In response to these limitations, the s-Nautilus profiler was developed [6]. It is an autonomous device designed to continuously monitor a variety of environmental parameters along the water column. This profiler uses a ballast system to change its depth, allowing it to take measurements along the water column, from the bottom to the surface. However, this s-Nautilus profiler is not capable of stopping at a specific depth. In addition, the size and weight of this profiler (21 kg) requires at least two operators to transport and install it.

The stratification of the marine water column [3] requires instruments capable of stopping at specific depths to obtain precise and stable measurements of environmental parameters. This capability is crucial for a better understanding of oceanographic processes and interactions between different components of the marine ecosystem.

Therefore, the aim of this work is to design an improved and miniaturized version of the profiler, called μ-Nautilus. This new device will retain the basic capabilities of the previous model but will focus on improving its size and weight to facilitate its transport and deployment in the field by a single operator. In addition, the μ-Nautilus will be designed to stop precisely and stably at specific depths for a configurable period of time, using ballast tanks as the only control action. This approach will enable more precise and detailed measurements of environmental parameters along the water column, improving our understanding of the marine ecosystem and our ability to manage it effectively.

This paper presents the methodology used to design the profiler and control its depth. In addition, the resulting profiler and its characteristics are presented, as well as the results obtained in terms of control. Finally, a detailed discussion is given, and the conclusions drawn from the results obtained are presented.

Materials and Methods

Profiler design

The profiler discussed in this paper has been designed to meet specific monitoring needs in the marine environment. It builds on the fundamental capabilities of its predecessor, the s-Nautilus profiler.

On the one hand, it requires adaptable specifications to be able to measure various physical parameters and accommodate different sensors, such as dissolved oxygen, temperature, and electrical conductivity, among others. Additionally, it must support a data transmission protocol and have a communication design that ensures knowledge of the lagoon status in near real time. Firstly, Wi-Fi communication will serve as the conduit for operator-profiler interaction, allowing for the adjustment of operational parameters. Secondly, Sigfox communication will facilitate the transmission of recorded measurements to a server.

To address logistical concerns regarding the maintenance of the lagoons, it is necessary to set a minimum autonomy of three weeks. This will ensure minimal human intervention, while allowing for the necessary maintenance to be carried out on the sensors, which are prone to fouling in the Mar Menor. Consequently, the mechanical, electronic and software design are emphasized by energy autonomy specifications.

In terms of mechanics, the design must ensure isolation, withstand pressures of up to two bar, and use readily available components to ensure replicability and cost-effectiveness.

Finally, the entire design has been based on the objective of achieving a lightweight, compact profiler for the purpose of facilitating transport and installation by a single operator. Consequently, the design of the s-Nautilus predecessor has been reduced to half the weight.

On the other hand, the operational mode of this profiler is based on a sequence of states. State 0 represents the initial deployment phase, during which the profiler should be situated on the surface with the ballast tank empty and Wi-Fi communication activated to allow the user to initiate the operational cycle. Upon activation, the date and time are updated via Sigfox, Wi-Fi is deactivated, and State 1 is initiated. At this state, the profiler initiates the immersion process by filling the ballast tank. Upon reaching the bottom, the power sources are deactivated, and the microcontroller enters a deep-sleep mode, transitioning to State 2. During State 2, the profiler remains stationary on the seabed for a predetermined period, with all functions deactivated to minimize energy consumption. Upon the expiration of this period, the profiler transitions to State 3. In State 3, the power sources are activated to preheating the sensors for measurement, and the profiler initiates the control cycle. The device measures a series of parameters at various locations: at the seabed, rising to each set depth, and finally at the surface. Subsequently, in State 4, the tank remains empty, and Wi-Fi communication is reactivated to allow the user to adjust control parameters if necessary. The sensor measurements are transmitted via Sigfox. Subsequently, the cycle commences once more in State 1.

Control design

To design a depth control system, it was determined that it would be inadvisable to use actuators that must be installed externally on the profiler structure, such as thrusters [7]. This is because this type of actuator requires frequent maintenance as a result of the prevalence of fouling in the Mar Menor. Therefore, depth control will be achieved using Variable Ballast Systems (VBS).

The μ-Nautilus profiler is equipped with a single ballast tank, specifically the Kolbentank XP750-12V 540 from Alexander Engel KG (Richard-Wolf-Str. 2, D-75438 Knittlingen, Germany), with a capacity of 750 cm³. The time required for the piston to complete a full stroke is 18 seconds [2].

The system modelling considers the different principles that influence the process: Archimedes' principle, hydrodynamic forces, and the weight of the profiler together with the ballast in the tank.

The thrust generated by the external geometry of the profiler and its weight are known. The force exerted by the ballast at each moment is determined by the piston position measured by a Hall Sensor for Compact Tank Switch CTS2.2 from Alexander Engel KG (Richard-Wolf-Str. 2, D-75438 Knittlingen, Germany).

With a total of 388 pulses in a complete stroke and a piston length of 0.2 m with a cross-sectional area of 0.00375 m², the force exerted by the tank can be modelled in Formula 1.

$$F(t) = \rho_w \cdot \frac{p(t) \cdot V_{max}}{p_{max}} \cdot g \qquad 1$$

where ρ_w is the density of water, V_{max} is the maximum volume of the tank calculated over the piston length and cross-sectional area, p_{max} is the maximum number of pulses per stroke, $p(t)$ is the number of pulses in each time interval t, and g is the gravitational constant.

The control method exhibits a slow response due to the sluggish action of the piston when introducing or expelling ballast (approximately 18 seconds per stroke). It is crucial to limit the piston travel around the neutral buoyancy point to minimize overshoots.

Given the inherent inertia of ballast control, a cascade control scheme has been designed, comprising three control loops from the innermost to the outermost: piston position, speed of the vertical component of the profiler and depth, respectively. The piston position controller operates in three states: fill, empty, or stop. The velocity and depth controllers of the profiler are PID controllers with saturation limitation, which prevents outputs from exceeding system limits.

The Figure 1 represents the cascade control described.

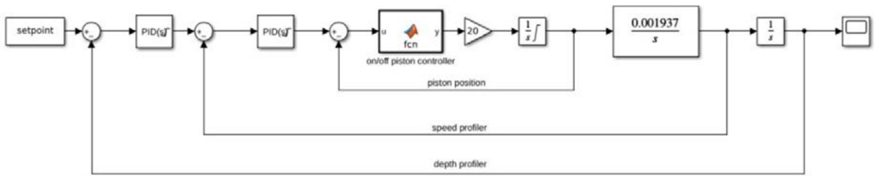

Figure 1 – Cascade control implemented in the μ-Nautilus profiler for depth control.

Energy consumption tests

The application of this profiler will focus on the performance of complete cycles (see “Profiler design” in this section) every six hours. These will comprise measurements of the seabed at four intermediate depths and at the surface.

The ballast tank is powered directly by four 3S Lipo batteries with a capacity of 3200 mAh and a voltage of 11.1 V 80C from Zee Power CO., Limited (Lucky Centre, Wan Chai, Hong Kong).

The electronic board is powered by five 1S Li-Ion batteries with a capacity of 3350 mAh and a voltage of 3.6 V from LG CHEM (Yeongdeungpo-gu, Seoul, South Korea).

To determine the autonomy of the profiler, it was decided to perform complete cycles continuously while controlling at four intermediate depths. By determining the number of completed cycles, it is possible to establish the autonomy of the profiler in real conditions, which include the performance of cycles every six hours.

Testing methodology

The design of the controllers is achieved using MATLAB simulation software. Furthermore, to ascertain the efficacy of the μ-Nautilus profiler and the depth control response in a real-world setting, a test tank was installed at the Polytechnic University of Cartagena facilities to perform preliminary testing. The diameter of the tank is 0.5 meters, with a maximum depth of 2 meters. Subsequently, the dynamic behavior of the profiler was validated in the sea at the Real Club de Regatas de Cartagena (Spain) facilities.

Results

Structural results

The resulting profiler exhibits a set of key physical attributes, including a weight of 11 kg, a minimum diameter of 50 mm, and a maximum diameter of 250 mm for the main body. Additionally, the profiler has a maximum height of approximately 819 mm, which includes a lower structure functioning as a landing platform, elevating the bottom of the profiler by 88.6 mm. This design element serves to prevent equipment damage and minimizes impact with underwater flora.

The external structure has been fabricated using commercial PVC pressure components. Additionally, other components have been created using PLA through a 3D printer. These include mounts for external sensors mounted on the outside of the profiler, as well as an internal structure housing various electromechanical component, such as the power supply, the ballast tank for depth adjustment, a control electronic board, and a communication antenna.

Figure 2 depicts the external and internal design of the μ-Nautilus profiler.

Figure 2 – External and internal architecture of the μ-Nautilus profiler.

Depth control results

The tests were conducted in both a test tank and in the sea at the Real Club de Regatas de Cartagena. However, for the sake of brevity, only the results obtained are presented for the latter scenario with more challenging conditions.

Figures 3-5 present the control results obtained at the Real Club de Regatas.

Figure 3 illustrates the depth evolution when control was applied at 4.5, 3.5, 2.5, and 1.5 meters, with each setpoint established for 120 seconds.

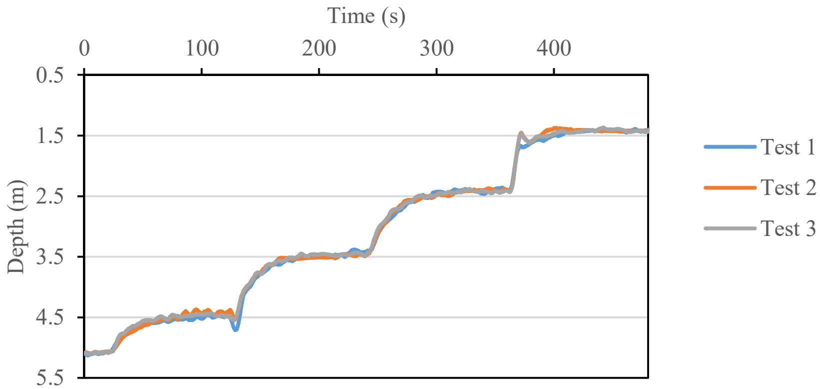

Figure 3 – Depth evolution for 4.5, 3.5, 2.5, and 1.5 meters, setting each setpoint for 120 seconds.

The user is afforded the option of configuring the dwell time at each depth. To reduce energy consumption, it was determined that once the profiler reached the setpoint within the established error range, it would remain at that depth for 20 seconds. This configuration allows a reduction of time for the actuator operation if the prevailing environmental conditions are optimal. The outcomes of this type of control are presented in Figure 4.

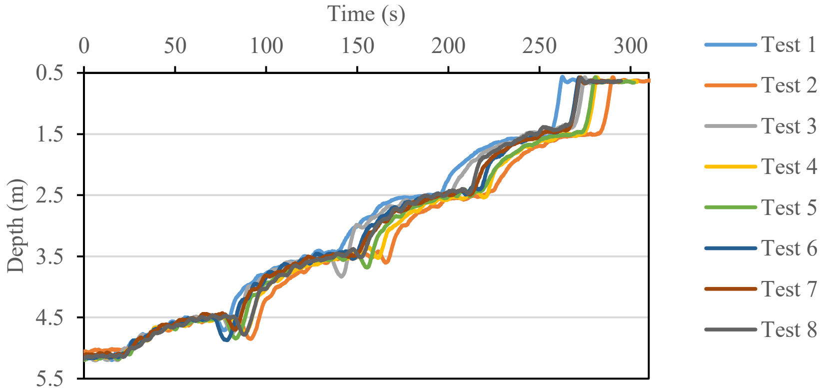

Figure 4 – Depth evolution for 4.5, 3.5, 2.5, and 1.5 meters, remaining at each setpoint within the error range for 20 seconds.

Figure 5 illustrates the absolute depth error in relation to the established setpoint over the past 20 seconds of control at each depth level.

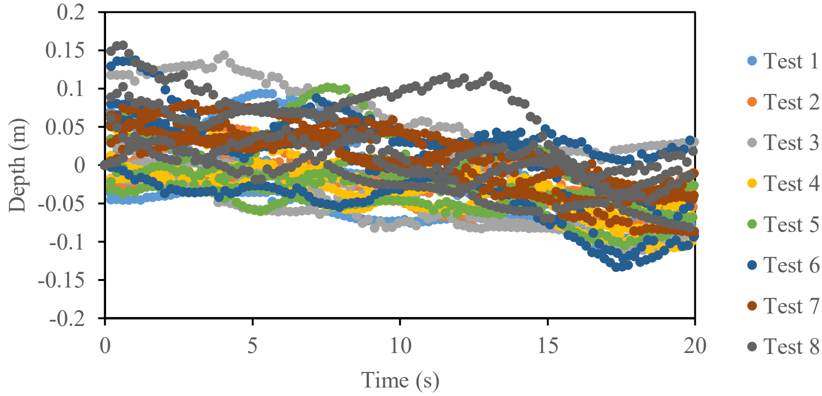

Figure 5 – Depth error obtained during the last 20 seconds of control.

Discussion

The utilization of commercial PVC pressure components for the external structure of the μ-Nautilus profiler confers flexibility upon future design modifications, while simultaneously reducing the associated costs. Furthermore, this design allows for the simultaneous disassembly of all components, thereby simplifying maintenance procedures.

The dimensions and weight of the μ-Nautilus profiler permit its transportation and installation by a single operator, thereby facilitating its deployment and enabling the rapid replacement of profilers when necessary for maintenance.

Furthermore, the more compact profiler with a single ballast tank is less costly in terms of materials than the s-Nautilus profiler.

Regarding control, Figures 3 and 4 illustrate the satisfactory and configurable depth control of the profiler. It was determined that once the profiler reaches the setpoint within the specified error range, it should remain at that depth for 20 seconds to minimize energy consumption, as illustrated in Figure 4.

This dwell time was selected as it is considered sufficient to allow for the precise capture of the marine parameters of interest, although it can be adjusted according to the specific requirements of the application.

Figure 5 illustrates that the depth error remains within the range of ±15 cm. Both the dwell time at the setpoint and the error range are configurable. However, prolonging periods at a specific depth or reducing the error margin will entail longer actuator activity, thereby increasing energy consumption and decreasing the autonomy of the profiler.

Further research has determined that a control for four intermediate depths and provided with four batteries of 3200 mAh and 11.1 V to run the ballast tank and five batteries of 3350Ah and 3.6 V for the rest of the electronics, the profiler can complete 192 cycles. Given that these devices will be deployed in the Mar Menor for sampling every six hours, the 192 cycles represent an autonomy of 48 days. This time is more than enough considering that it is recommended to clean the sensors every three weeks due to the predominant fouling in the Mar Menor. It is important to note that, while the tests were conducted in a real environment, it was protected and experienced fewer disturbances than those encountered in the Mar Menor. Consequently, further study is required to elucidate the control dynamics in the actual application environment.

Conclusion

This study is concerned with the development of the autonomous profiler μ-Nautilus, which has been designed to operate in shallow environments such as the saltwater lagoon Mar Menor. The reduction in weight and size of this profiler facilitates its transportation and installation, both for laboratory testing and field implementation. Furthermore, the capacity of the profiler to maintain a specific depth enables precise monitoring of marine parameters.

The profiler offers configurable control parameters, including dwell time, depth error, and depth setpoint, as well as operational parameters such as the interval between cycles. This versatility renders it an attractive proposition for the continuous observation of shallow marine environments, which are of crucial importance for the modelling of the hydrodynamics of Mar Menor and the implementation of preventative measures against unfavorable events such as anoxia episodes.

It is important to note that while the results are presented in a real environment, further study of its performance in Mar Menor, the actual application scenario, is still required. This would assist in the determination of its operational dynamics in the real application environment.

Acknowledgements

This study formed part of the THINKINAZUL programme and was supported by MICIU with funding from European Union NextGenerationEU (PRTR-C17.I1) and by Fundación Séneca with funding from Comunidad Autónoma Región de Murcia (CARM).

The authors are grateful to "Real Club de Regatas" (Cartagena) yacht club for letting us their facilities to conduct the tests.

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ESTIMATING THE AMOUNT OF BALLAST WATER FROM SHIPS IN THE MEDITERRANEAN: ANTALYA BAY CASE STUDY

Ömer Harun Özkaynak, Gönül Tuğrul İçemer

Abstract: This study estimated how much ballast water ships can produce in the Gulf of Antalya, an important port city in the Mediterranean. The data used in the calculation was obtained from AIS (Automatic Identification System) of the ships arriving in Antalya Bay between 2018-2021. These ships' ballast water was determined using information from DWT (deadweight tons) using the methods given in the literature. It was calculated as a percentage of DWT according to ship types. As a result of the calculation, it has been determined that three to six million metric tons of ballast water produced in four years originates from bulk cargo ships. In addition, when other ship types are included in the Gulf of Antalya, it is evaluated that 7-12 million metric tons of ballast water may be produced, posing a severe threat to the Mediterranean ecosystem.

Keywords: Ballast Water Management, Ship Ballast, Mediterranean Ballast Water.

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Ömer Harun Özkaynak, Gönül Tuğrul İçemer, *Estimating the Amount of Ballast Water from Ships in the Mediterranean: Antalya Bay Case Study*, pp. 977-987, DOI: 10.36253/979-12-215-0556-6.85

Introduction

While navigating at sea, ships use ballast water to navigate safely in adverse weather conditions, ensuring their balance and stability when empty [1]. Ships take water into their ballast tanks when they are not taking on cargo. But the amount of ballast water a ship will discharge will vary depending on the cargo's weight. For example, all ballast must be unloaded to adjust the heel and trim of a ship carrying a heavy cargo load.

Although many ports are open to international trade in the Mediterranean, most do not have intercontinental importance. These ports connect to central ports worldwide, while local trade connects them to secondary Mediterranean ports. Therefore, the intense ship traffic in the Mediterranean mainly includes ships passing through transit.

Central ports in the Mediterranean are the sea at most significant risk, as they are most open to the intercontinental transfer of harmful aquatic organisms, including alien invasive species, and, therefore, to the primary introduction of Mediterranean invasive species. Shipping within the Mediterranean facilitates the transfer of species brought to central ports and, as a result, causes the secondary transfer of invasive species [2] [3].

The number of alien species in European seas has different patterns than in other parts of the world; this is because more than 50 % of introductions occur in the Mediterranean, with more than 650 species recorded, of which at least 325 are resident [4].

The ship's water from the marine environment to the ballast tanks contains suspended solids and various organisms [5]. Studies on the content of ballast water have shown that multiple plant, animal, and bacterial species can survive in ballast tanks and ballast water for a long time [6] [7] [8]. Some studies have shown that various organisms can survive in ballast tanks for several months or longer [9].

It has been determined that a species contained in the ballast water that each ship takes from one port and discharges to a different port has the potential to cause a significant negative impact on the receiving environment [9]. For example, after species introduction from one seashore to another via primary ballast water, secondary dispersal may occur in the receiving coastal waters by recreational boats or fishing activities [10]. In addition, other dynamic factors such as weather and sea conditions that ships may encounter while cruising, approaching shallow waters, and fuel and diesel consumption during the journey may also require ballast water operations [5]. For example, this may be the case for larger bulk carriers, which may load water into some central cargo holds to continue sailing safely in a "heavy ballast condition" when encountering heavy sea conditions.

Ship ballast capacity is determined by the ship's cargo capacity and the speed at which cargo operations can be carried out. The more cargo a ship can carry, the more ballast may be required when there is no cargo on board, and the more cargo operations there will be.

As defined in IMO: “Ballast Water Management means mechanical, physical, chemical and biological processes, alone or in combination, to remove, render harmless or prevent the uptake or discharge of Harmful Aquatic Organisms and Pathogens in Ballast Water and Sediments.”

The amount of ballast water discharged into the sea by ships on a global scale is estimated to be more than 10 billion tons [11], and Endresen (2004) [12] and other similar studies, it is estimated to be 3.5 billion tons. When these evaluations were made, approximately 5 billion tons of cargo were transported annually in world maritime trade. The cargo transported by maritime trade was 4.651 billion tons in 1995 and 5.871 billion tons in 2000 [13]. Endresen et al. (2004) [12] evaluation, it was accepted that world maritime trade is 8.734 billion tons of cargo, 5.434 billion tons of international, and 3.3 billion tons of national naval trade.

Ships carry many aquatic invasive species and different pollutants with the ballast water they take from the sea in another port [14] [15]. With increasing maritime trade and the number of ships sailing in the seas, the volume of ballast water carried will increase; therefore, the amount of pathogens and various pollutants in it will increase [16].

Ballast water capacity varies as a function of cargo carrying capacity and ship type, with an average value of 33 % of the ship's DWT [17]. The BWDA model considers all this, so the estimated discharge would be 33 % of the cargo volume in world maritime trade when excluding light cargo. It has been reported by IMO (2017) that approximately 10 million tons of ballast water containing different marine species are transferred from one port to another in the world [18].

According to studies conducted in previous years, 3000÷4000 different species are transported worldwide by ships every day [19]. More recent estimates indicate that the number of species transported by ships is likely around 7000 each day, and this does not include the transfer of microorganisms such as bacteria and pathogens [20]. Additionally, Tolian et al. (2020) [21] in the Persian Gulf, as a result of the analysis of ballast water samples taken from 32 ships, the amounts of Ni, Cd, Pb, and Cu heavy metals were 46.55, 3.93, 5.36, 58.83 and 26.41, 2.12, 2.59, 23.54 ppb (parts per million), respectively, and the values were determined to be above acceptable values.

Countries have coastal monitoring programs, but in most cases, there are no sampling stations at ports where ballast water is discharged or received. Early detection of new species that may be present in ballast water increases the possibility of quickly preventing the damage they may cause to the marine environment [22]. Thus, harmful species can be detected and eliminated early [23].

The primary goal of international and national legislation on ballast water is to prevent the effects of the discharge of harmful wastes containing Aquatic Organisms and Pathogens (HAOP) through ballast water. The most fundamental international legal regulation in this regard is the International Convention on the Control and Management of Ship Ballast Water and Sediments, London 2004 BWM Convention. The Convention entered into force on 8 September 2017, and 81 states ratified it, indicating that it has been accepted by 80.76 % of the total tonnage of the global merchant fleet as of 5 August 2019 [24]. This contract implements ballast water management in two ways: Ballast Water Exchange (BWE) and Ballast Water Treatment (BWT) according to D-2 and D-1 standards. In the BWE method, ships exchange 95 % of their ballast water in waters at least 200 m deep and at least 200 nautical miles from the nearest shore, according to the International Maritime Organization (IMO) Guidelines [25] [26]. It requires that the number of living organisms in the discharge of ballast water be below the limits established by rule D-2. The table created by David and Gollasch 2008 [27] regarding the standards that ships should apply according to their construction date and ballast water capacity has been rearranged and given in Table 1.

Some countries have ratified the BWM convention and implemented its requirements. Most of these requirements are based on the IMO Ballast Water Exchange (BWE) Standard (Regulation D -1). Some countries have implemented the Ballast Water Performance Standard (D-2), and a few have implemented applications for onshore ballast water intake facilities. In some countries, ships must keep a BWM plan and a ballast water record book [28].

If the ballast water exchange is impossible in some countries, other measures such as BWE or other water treatment practices should be implemented in a designated coastal area. For example, Canada has no regulations requiring saltwater treatment but does offer it as an option for ships arriving with tanks with salinities below 30 ppt. This method can only be applied if the number of tanks to be treated is small or for the remaining ballast [29].

As it is known, the Regional Marine Pollution Emergency Response Center (REMPEC) for the Mediterranean serves as the regional coordination organization. Regarding ballast water management, the Mediterranean strategy document created by REMPEC and the harmonized regulations for BWM in the Mediterranean region has also been adopted [30].

From 1 October 2012, ships leaving the Mediterranean Sea and bound for destinations in the North-East Atlantic or the Baltic Sea, and ships arriving in the Mediterranean from these areas, will be in the North-East Atlantic area and at least 200 nautical miles from the nearest land and at least The obligation to exchange ballast water in waters with a depth of at least 200 m has begun to be implemented. If this is not possible for operational reasons, BWE should be conducted as far as possible from the nearest land, at least 50 nautical miles from the nearest land, and in waters at least 200 m deep [31].

In addition to ballast exchange rules for ships arriving and leaving the Mediterranean, it has become mandatory for ships to have a Ballast Water Management Plan and keep records of all ballast water operations [28] [31].

Three methods for Ballast Water Exchange have been identified by IMO [32]:

Sequential method: A ballast tank is emptied and then refilled with reserve ballast water to achieve at least a 95 % volumetric change.

Flow method: A process in which water in one ballast tank is pumped into another, allowing the water to flow through overflow on the deck or other arrangements.

Dilution method: A process in which water in one ballast tank is filled from the top of another and simultaneously discharged from the bottom at the same flow rate, thus maintaining a constant water level throughout the BWE.

Besides the requirements that must be met regarding the BWE methods applied, a ship must also meet the criteria regarding where the BWE will be carried out. A ship must first perform ballast water exchange at a distance of at least 200 nautical miles from the nearest land and in a water depth of at least 200 m. If this is not possible, BWE should be carried out as far away from the nearest land, at least 50 nautical miles from the nearest land, and in waters at least 200 m deep [33].

Table 1 – The original phase-in plan of the ballast water performance standard (Regulation D-2) about the ballast water exchange standard (Regulation D-1) [27].

Ships built	BW capacity (m^3)	Phase in of the D-2 standard of the BWM Convention							
		2009	2010	2011	2012	2013	2014	2015	2016
Before 2009	1500 - 5000		D-1 or D-2					D-2	
After 2009	1500-5000		D-1 or D-2						D-2
2009	<5000		D-1 or D-2 -				D-2		
After 2010	<5000	-				D-2			
2009- 2012	>5000		D-1 or D-2						D-2
After 2012	>5000		-				D-2		

Suppose the depth and distance requirements mandatory for BWE cannot be met. In that case, a ballast water exchange area (BWEA) may be determined by the standards specified by IMO in consultation with other neighbouring port states.

The amount of ballast water discharged into the sea from ships engaged in international maritime trade is estimated to be 3.1 billion (3.1x109) tons per year [5]. According to the "Ballast Water Performance Standard Regulation" determined by IMO (International Maritime Organization), it is mandatory for ships performing ballast water management to have a ballast water treatment system that will meet the standards specified in Table 2. (D-2 standards) in the ballast water to be discharged. However, this obligation has been applied to ships produced since 2009.

Table 2 – Ballast water standards can be discharged into the sea [33].

Microorganism Category	Regulation
Plankton, Length > 50 µm	< 10 1/ m^3
Plankton, Length 10-50 µm	< 10 1/mL
Toxicogenic *Vibrio cholerae*	< 1 cfu (colony forming unit) /100 mL
Escherichia coli	< 250 cfu/100 mL
Intestinal Enterococci	< 100 cfu/100 mL

Although the D-2 standard introduced by IMO leads to a significant reduction in the number of released organisms, it is estimated that it cannot prevent 100 000 different species from entering the marine environment, assuming that ships carry up to 100 000 tons or more of ballast water and approximately 10 000 tons of this is discharged into the sea. Another weakness of the D-2 standard is that it does not take into account organisms below 10 µm (minimum size), such as harmful algae (for example, Phaeocystis spp., Pfiesteria spp., and Chrysochromulina spp.) [5].

The study aims to estimate the amount of ballast water originating from ships in the Gulf of Antalya, which hosts one of the important ports of the Mediterranean, and to guide the studies on ballast water in the coming years regarding its possible effects. This provides a basis for structural and legal regulations that can be taken on this subject by ensuring that the extent of the ecological impacts that ballast water may cause in the Mediterranean is estimated.

Material and Methods

Calculating the Amount of Ballast Water a Ship Can Create

General cargo and Ro-Ro ships generally use around 20 % of their DWT and even more than 40 % of ballast water, with some exceptions [5]. In addition, ships intended to transport liquid and dry bulk cargo, such as tankers and dry cargo ships, require significantly more significant amounts of ballast water, often between 30 % and 50 % of their DWT. This means using more than 100 000 m^3 of ballast water per ship.

A summary of the ballast water capacities for the main ship types identified by different authors and the types of ships placed in the Anatolian Gulf is presented in Table 3 [34].

Table 3 – Ballast water amounts of ships according to their DWT size [34].

Vessel type/ DWT (Ton)	AQIS (1993) [35]	Carlton et al. (1995) [36]	Walters (1996) [37]	Hay and Tanis (1998) [38]	Suban (2006) [17]	This Study
Cruise Ships	33	-	38	-	43	33-43
Bulk Cargo	-	43	41	60	33	33-60
Bulk Cargo /250 000	30–45	-	-	-	-	30-45
Bulk Cargo /150 000	30–45	-	-	-	30–45	30-45
Bulk Cargo /70 000	36–57	-	-	-	30–45	30-57
Bulk Cargo /35 000	30–49	-	-	-	33–57	30-57
Tanker		38	26		-	26-38
Tanker 100 000	40–45	-	-	-	-	40-45
Tanker/40 000	30/38	-	-	-	43	30-43
Container		32	30	30–60	35	30-60
Container /40 000	30–38	-	-	-	28–40	28-40
Container /15 000	30	-	-	-	30	30
General Cargo		-	35	30–60	29	29-60
General Cargo /17 000	35	-	-	-	-	35
General Cargo /8 000	38	-	-	-	-	38

The ballast water capacity of a ship varies as a function of cargo carrying capacity and ship type [12]. With this information, the annual amounts of ballast water carried can be estimated as a function of the total cargo carried annually. However, the amount of cargo carried varies widely. Since this is the case, it would be a more accurate approach to calculate the amount of ballast water according to the ship's DWT.

Table 3 shows that the amount of bilge water that may occur depending on the ship type can be determined according to different percentages according to DWT. According to previous studies, this study calculated the minimum and maximum amount of ballast water that can be formed using the smallest and largest ratios. In this study, the values used to calculate a ship's ballast water capacity are also given in Table 3.

Determination of the Amount of Ballast Water That Can Be Created by Ships in the Gulf of Antalya

The information on tankers, bulk cargo, general cargo, containers, and passenger ships cruising in Antalya Bay between 01 January 2018 and 31 December 2021 was tracked and recorded via AIS (Automatic Identification System). The region where ship movement information is recorded is shown in Figure 1. The amount of ballast water ships sailing in the area in question was calculated using DWT information. They were using the percentage rates given in DWT information Table.3, the minimum and maximum amount of ballast water ships can carry in Antalya Bay has been calculated.

Figure 1 – Registration area where ship information is recorded.

Results and Discussion

The number of ship movements and DWT averages according to passenger ship types in Antalya Bay between 01 January 2018 and 31 December 2021 are given in Table 4.

Table 4 – Movement numbers and DWT averages of ships cruising in Antalya Bay between 2018-2021.

Ship Type	Number of Ship Movements	DWT Average (Ton)
Tanker	261	22848.57
Container	267	23930.46
General Cargo	526	7000.07
Bulk Cargo	244	41244.83
Cruise ship	14	3436.357

The amount of ballast water that can be produced by the types of ships sailing in the Gulf of Antalya has been calculated using the percentage rates according to the DWT given in Table 3. The maximum and minimum totals of estimated ballast water amounts are shown in Table 5. While calculating the ballast water amounts of the ships, it is not taken into account that they will not receive ballast water when they arrive loaded and will use some of their ballast water capacity according to weather and sea conditions to ensure the ship's stability. These were not taken into account because, in a previous study conducted in Koper Port, it was determined that ships discharged more than 80 % of their ballast water [39]. In addition, in this study, the amount of ballast water created by ships was estimated previously. As stated in a survey, it was found that the ballast water coming to a port is critical when evaluated in terms of the content of ballast water [3]. In the ballast water sampling study carried out in Koper Port (Slovenia), it was determined that ballast water coming from ports in the same region (Mediterranean and mostly Adriatic Sea) also contained non-native species that have not yet been recorded [2].

Table 5– Ballast water amounts of ships cruising in the Gulf of Antalya in 2018-2021.

Ship Type	Minimum Amount of Ballast Water (Ton)	Maximum Amount of Ballast Water (Ton)	Annual average (Ton)
Tanker	2 107 945.1	2 628 075.51	657 018.8775
Container	1 589 642.88	2 477 380	619 345
General Cargo	-	1 339 794.37	334 948.5925
Bulk Cargo	3 019 121.4	5 387 920.14	1 346 980.035
Cruise ship	15 875.97	20 686.87	5 171.7175
Total	6 732 585.35	11 853 856.89	2 963 464.22

When Table 5 is examined, it is seen that the bulk carriers have the highest amount of ballast water, which is evaluated to have a capacity of approximately 8.5 million tons for four years. It is seen that the annual amount of ballast water varies between 619÷1 346 980 tons. Since the amount of ballast water discharged into the sea by ships on a global scale was previously estimated to be more than 10 billion tons, and in other similar studies, it was calculated to be 3.5 billion tons [11] [12], the amount of ballast water calculated in this study is also calculated in the Mediterranean Sea. It can be said that it is mainly acceptable for the Gulf of Antalya, one of Turkey's essential traffic lines.

Considering the total amount of ballast water calculated, the amount of ballast water is approximately 7÷12 million tons for four years. Considering that this amount comes from different ports of the world and takes ballast water from these ports and discharges it in the Gulf of Antalya, an important port city in the Mediterranean, it will not be difficult to predict the severe damage it will cause to the marine ecosystem. As the introduction mentions, ballast water contains many substances that harm the marine environment, including heavy metals and species foreign to the ecosystem into which it is discharged.

Conclusion

In this study, since ship ballast water amounts are calculated according to DWT information, these issues appear as limiting factors for the calculated ballast water amount since it cannot fully show the quantity of ballast water on the ship, and ships will not receive ballast water when they take on cargo.

Estimating the amount of ballast water discharges alone will not be sufficient to determine the harmful effect of ballast water on the marine ecosystem. In future studies, when samples are taken and the amount of harmful aquatic organisms and pathogens that may be found in ballast water is evaluated, the effects of the results on the marine environment will be more clearly visible.

Another severe issue from this study is that the intake of ballast water by waste reception facilities in ports and its strict control can prevent the ecosystem degradation caused by ballast water, which poses a significant threat to the Mediterranean and the World seas. However, no legal regulation gives port waste reception responsibility for ballast water.

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EMODNET DATA INGESTION A KEY RESOURCE FOR THE MARINE SCIENCE COMMUNITY

Leda Pecci, Paolo Diviacco, Mihai Burca

Abstract: Marine and coastal data management is crucial for scientific research, economic activities, and environmental monitoring. Marine data is collected from different sources using various tools and methodologies. There are several methods used for formatting marine data, but to put them in a standardized form takes time, effort and knowledge. To overcome the technical difficulties involved in submitting data, a group of 41 international organizations, led by HCMR (Greece) and MARIS (The Netherlands), is active in the EMODnet Data Ingestion project. Their goal is to simplify the process of data acquisition and transformation, ensuring data becomes interoperable and increasing the availability of marine data. By providing a structured platform for the submission, management, and dissemination of marine datasets, the project fosters an environment where data can be easily accessed, shared, and utilized by a wide range of stakeholders, including researchers, policymakers, and public. This paper presents EMODnet Data Ingestion services within the framework of the broader EMODnet. Examples of data sharing and important aspects of the EMODnet Data portal are delivered.

Keywords: Data submission, Marine open data, interoperability, data sharing

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Leda Pecci, Paolo Diviacco, Mihai Burca, *EMODnet Data Ingestion a key resource for the marine science community*, pp. 988-998, DOI: 10.36253/979-12-215-0556-6.86

Introduction

A holistic approach to environmental sustainability requires addressing global challenges such as climate change and sustainable management of marine resources that rely on data analysis. In the world of marine research, the need for large amounts of reliable and accessible data is critical. In Europe, several initiatives and infrastructures have been developed to improve the collection, storage, interoperability, accessibility and usability of marine data. Even though EU funds and the substantial progress in ocean data management have made possible the implementation of different ocean data infrastructures such as SeaDataNet (https://www.seadatanet.org/) and EMODnet (https://emodnet.ec.europa.eu/en), a large quantity of valuable data remains inaccessible.

Evidence

Ocean data sharing and use require technical and cultural solutions to overcome challenges in uploading, aggregating, and navigating, ultimately to make the data available [1].

EMODnet Data Ingestion plays a crucial role in advancing the principles of open data and data reuse within the marine science domain. As an essential component of the EMODnet initiative, this platform serves as a catalyst for enhancing the accessibility, usability, and sharing of marine datasets across Europe. To understand the significance of EMODnet Data Ingestion, it is essential to be aware of what EMODnet represents.

EMODnet was funded by the European Commission, under the Integrated Maritime Policy, to address fragmented marine data collection, storage, and related issues across Europe [2].

The idea behind EMODnet emerged following the publication of the 2006 Green Paper "Towards a Future Maritime Policy for the Union: A European Vision for the Oceans and Seas" [3] that was a pivotal document aimed at initiating a comprehensive discussion on the future of maritime policy within the European Union [4].

The EMODnet pilot projects began in 2009. In 2010, the European Commission (EC) released the Marine Knowledge 2020 communication, which aimed to enhance data availability and accessibility as well as to highlight the importance of marine data across Europe. This initiative was a step forward in recognizing marine data for sustainable growth and informed decision-making in maritime sectors. According to this document, the EC proposed funding for EMODnet to support its further development [5]. Implementing the objectives of the Marine Knowledge 2020 strategy EMODnet expanded its thematic portals, improving data accessibility by standardizing data formats and integrating various national, regional, and international databases. Collaboration and synergy with EU marine research initiatives, such as SeaDataNet and the Copernicus Marine Environment Monitoring Service (CMEMS), have contributed to the enhancement of EMODnet infrastructure [6].

EMODnet allows access to high quality and harmonised marine data and data products across Europe. The initial pilot projects focused on thematic areas such as biology, bathymetry, chemistry, geology, habitats, and physics, providing a foundation for a more integrated marine data infrastructure [7].

Currently EMODnet functions as the in situ marine data service of the EC, specifically under the Directorate-General for Maritime Affairs and Fisheries (DG MARE) (https://emodnet.ec.europa.eu/en/about_emodnet).

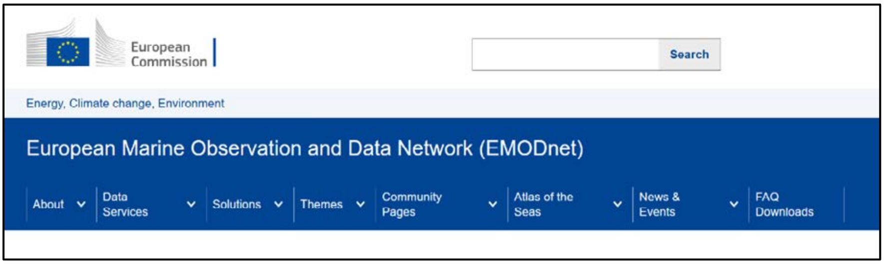

Figure 1 – The EMODnet portal.

Given that the partners involved in EMODnet are not directly funded by the European Commission to provide marine data, their collaboration with other initiatives is essential for the success of the network. EMODnet serves as a data aggregator service, relying on upstream global, pan European and coastal in situ observing networks (GOOS, EuroGOOS, European Marine Research Infrastructures), and associated data assembly and processing infrastructures such as National Oceanographic Data Centres, and SeaDataNet (https://marine.copernicus.eu/news/european-situ-marine-data-service-landscape).

EMODnet Data Ingestion fosters an environment conducive to collaboration, informed decision-making for policy makers, and sustainable management of marine resources. The project website incorporates interactive features that encourages collaboration and engagement (https://www.emodnet-ingestion.eu). The core of the portal is the user-friendly "Data Submission Service", which simplifies the process for data producers to provide their datasets.

This service breaks down the submission into manageable steps, allowing organizations to upload their data with minimal barriers. This streamlined approach exhortes a wide range of stakeholders, including research institutions, public agencies, and private organizations, to share their marine data by implementing a simplified approach.

An online form, representing a comprehensive tool for users to enter the necessary information, facilitates the data submission service. This digital interface aids the submission process, guiding the data submitter through each step with ease by a series of structured fields, ensuring that all relevant data is accurately captured and submitted in a systematic manner. In the initial phase of the 2-step data submission process, the data contributor fills in a selection of essential fields in the submission form and attaches a compressed archive (in zip format) that includes the datasets and accompanying documentation.

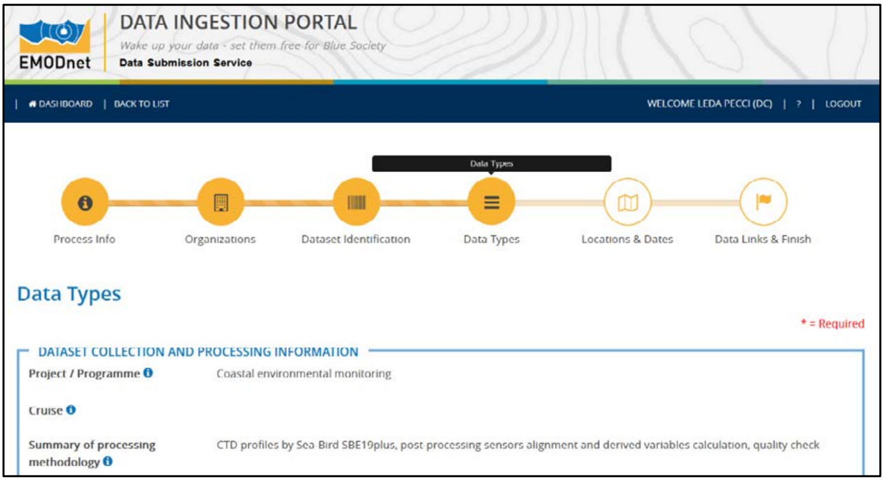

Figure 2 – The first phase of the data submission process.

A data center is chosen to support the completion of the submission process, in the first phase is in charge to try to replace free-text entries, written by data providers, with standardized terms and to make other adjustments in agreements with the data submitter. In the second phase the data center, in close collaboration with data submitter, improve and refine the datasets through a series of systematic processes aimed at improving the quality and usability of the data. Once the datasets has been inspected, their metadata have been finalized and any necessary processing has been performed, they are ready for integration into the national and European infrastructures, such as SeaDatanet, EurOBIS and ICES, which support EMODnet. This integration ensures that the datasets are accessible via the EMODnet portal, broadening their availability to a diverse spectrum of users.

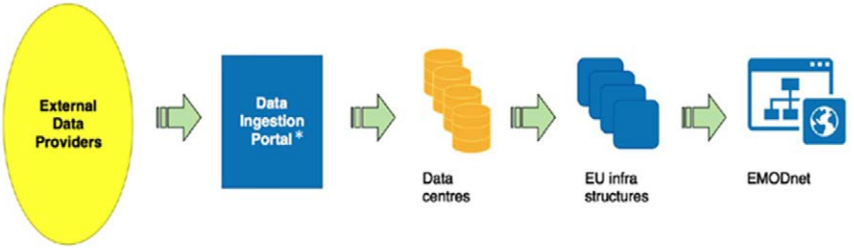

Figure 3 – Workflow from the submission to the publishing. Note: This graph was produced by Dick Schaap (MARIS).

EMODnet Data Ingestion community is creating a culture of open science that offers numerous advantages that enhance the scientific process and its societal impact. One significant benefit is the promotion of transparency and collaboration among researchers, which leads to improved trust in scientific findings. By making research data openly accessible, the academia community can replicate studies using the original data and methods, allowing them to verify the findings. Furthermore, scientists can engage with a wider audience, including policymakers, practitioners, and the public, fostering a more inclusive dialogue around scientific knowledge.

We strongly encourage the submission and use of open marine data expecting that, eventually, these practices will be widely adopted. Infrastructures like SeaDataNet utilizes SEANOE (SEA scieNtific Open data Edition) to enhance data sharing among researchers. By utilizing SEANOE's service, researchers can publish their data and obtain a DOI (Digital Object Identifier), free of charge [8]. Thanks to a strong connection between SeaDataNet and EMODnet Data Ingestion, datasets published in SEANOE are automatically replicated to the EMODnet Data Ingestion portal and published as if they were submitted directly.

One of the possible data types ingestible by Emodnet on which we here will report is anthropogenic underwater noise. This kind of pollution is gaining a lot of importance recently considering the explosion of marine traffic and port related activities.

Marine animals are highly dependent on sound to communicate with their environment. Sounds are crucial for foraging, communication, predator avoidance and general spatial orientation [9]. According to the EC Marine Strategy Framework Directive (MSFD), sounds that have negative effects are defined as noise, and indeed exposure to underwater acoustic noise affects marine life [10].

The effects of underwater noise on marine life encompass a wide range of phenomena, a subset of which are of detrimental ecological significance in terms of long-term consequences for populations. The effects of anthropogenic underwater noise include issues such as behavioral responses masking, hearing loss, physical and/or physiological effects, and even death [11] [12] [13].

To address such topics Istituto Nazionale di Oceanografia e di Geofisica Sperimentale – OGS, in collaboration with other institutions and companies, developed a low cost marine noise monitoring system (CORMA). The structure aims to reconstruct the acoustic pressure in a defined area through the deployment of a real time acquisition and transmission device installed on OGS buoys located within the area of the Gulf of Trieste (North Adriatic Sea). Further details on the acquisition system can be found in [14]. The system recorded two years of continuous data that are made public through the Emodnet Ingestion portal following the FAIR principles and metadata standards there designed.

Files available can be downloaded as standard .wav files that can be playback, processed and analysed using any acoustic data processing software. Data is sampled at 48 kHz 24 bit since the main objective of the project is to correlated underwater noise and marine traffic. Larger spectrum would mean that larger files should be transmitted which would create problems in energy consumption of the system, which being powered by solar panels and batteries need to be carefully tailored for the aim of the research. Data is stored in a central facility from which each recording can be accessed and downloaded. Each file stores 10 minutes of recording and is catalogued with an easy to be read timestamp that is shown also at filename level.

Analysing the data it is possible to identify the source of the noises. Low frequency that span large time recording can be associated with large vessels, while high frequency short duration signals can be associated with leisure boats.

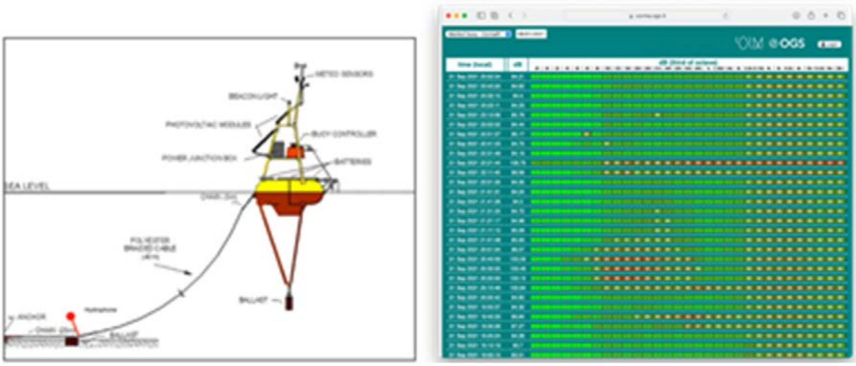

Figure 4 – Corma monitoring system (left) and data storage and access (right).

In our case the datasets are findable on web site of SeaDataNet https://www.seadatanet.org/Metadata/CDI-Common-Data-Index using “QUERY THE COMMON DATA INDEX (CDI) V5 DATA DISCOVERY AND ACCESS SERVICE”. The quickest way is to use the tool of “Free search” in a both way: by instrument type (hydrophone) or knowing previously the name of the project (Corma), getting a result as:

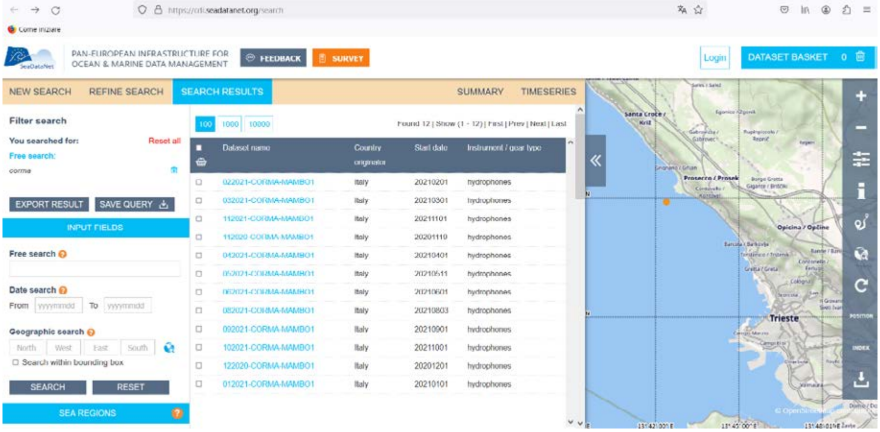

Figure 5 – Visualization of Corma data.

Once you select/click on the dataset(s) you can have access to the data adding it on the basket of SeaDataNet or more easily scrolling down on metadata till the link of the website of the data owner: https://corma.inogs.it/index.php?date=2021-06-01.

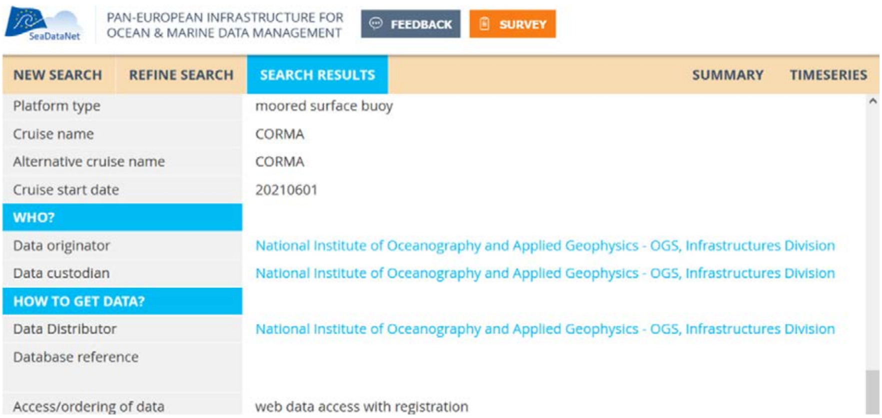

Figure 6 – Visualization of various metadata of Corma's data.

It is enough to change the daily date on the link address to view all data day by day.

Another way to retrieve data is by using the EMODnet service. EMODnet operates as a data service of the European Union, and so, its website is incorporated into the larger EC web framework.

There are different ways to access the data, the most direct is by navigating to the EMODnet portal, starting from a map-based web-page which serves as a primary resource for retrieving various kind of data, mainly organised by disciplines, at web address: https://emodnet.ec.europa.eu/geoviewer/.

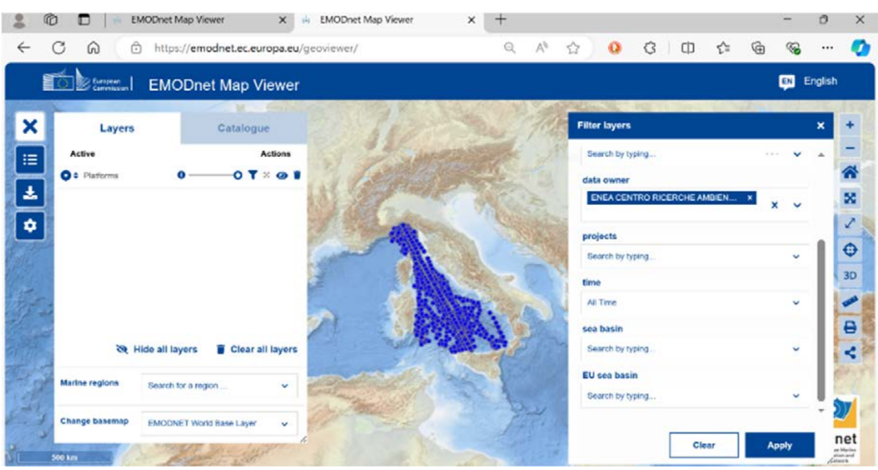

Figure 7 – Visualization of some ENEA's physics data in the Mediterranean Sea.

To activate a layer select it from the “Catalogue” tab, then go to the “Layers” tab. Clicking on the filter icon a list to select appears. It is possible to filter by name of the owner of the data or by other parameters.

Whereas, to search for data, by selecting an area on the map, it is necessary to click the "Download" button in the left toolbar and a button appears on the right side of the map. Click on it and then draw a bounding box on the map. On the right side of the menu appears the format in which you can download the data.

ENEA has shared a diverse array of data throughout the years, showcasing its commitment to collaboration. This data includes various kind of marine data belonging to different disciplines, some of which has been produced in partnership with other Italian institutions and associations.

Here, we want to present an example of citizen science data in the field of the Mediterranean studies: the MedFever project. The public–private partnership between ENEA, the University of Rome, “La Sapienza” and the MedSharks association, makes available valuable data. The MedSharks association is focused on the conservation and monitoring of shark populations in the Mediterranean Sea, but is also involved in various initiatives. This project engaged volunteers, from 12 diving centers, in collecting temperature data.

In 2021, a network of 12 small observatories, by means of marine probes, was established in the Tyrrhenian Sea, with the aim of collecting high-frequency measurements of temperature at standard depths [15]. This initiative was made possible through the collaboration of voluntary diving centers, who played an important role in the deployment and maintenance of the observational infrastructure.

Citizen science offers a unique opportunity for anyone, regardless of scientific background, to contribute to the well-being of our Seas. The collaboration of a working team of highly motivated people in the private sector, professional oceanophers and ocean data managers provides a major impact in the advancements of ocean research. This allows the sharing of a larger quantity of high quality data to a wider audience by using EU infrastructures and standards for the data and metadata.

To retrieve the data submitted by using the EMODnet Data Ingestion Service the simplest way is to go to the “Viewing Submission Service” and select one of the option available, as, for example, the button “Sea Areas” writing “Tyrrhenian Sea” and “ENEA” in the field “Free Search”.

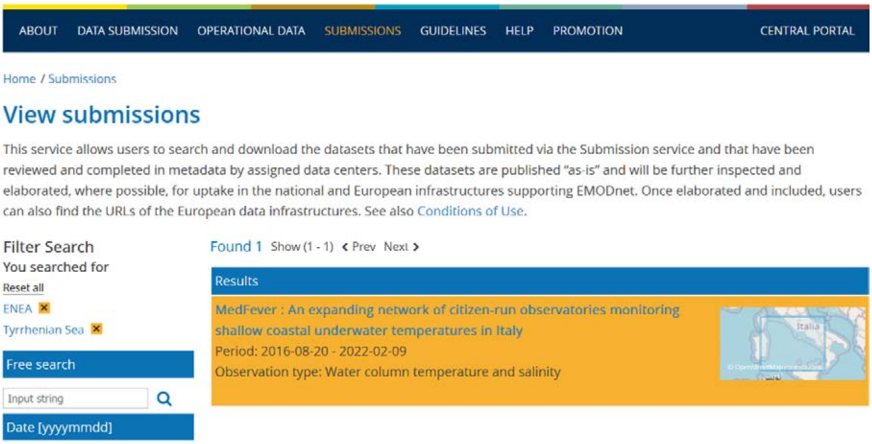

Figure 8 – Example on how to retrieve data in the "View Submissions" service.

Conclusions

The described initiative is designed to support the goals of EMODnet by promoting data reuse and adhering to open data principles, which are essential for effective marine resource management and environmental sustainability. In an era where global environmental challenges such as climate change, pollution, and biodiversity loss are increasingly prevalent, the sharing of ocean data emerges as an important means for dealing with these issues. Data reuse may have other purposes than those for which they were originally acquired. The FAIR (findable, accessible, interoperable, and reusable [16]) principles allow other stakeholders to make use of this data. The project has been playing an important role in advancing the practice of open data sharing, significantly shaping the behaviors and attitudes of researchers within the scientific community. By promoting the principles and the practices of making research data openly accessible, the project not only facilitates the dissemination of knowledge but also fosters a cultural shift among researchers regarding how data is perceived and utilized. This paper highlights the significant benefits that marine data sharing offers as well as the asistance provided by the EMODnet Data Ingestion portal. This portal offers technical support, provides resources and aids with marine data management, submission, and curation processes, and allows for high quality, well-documented data.

Acknowledgements

This paper represents the progress of a collaborative effort by a large and diverse group of marine scientists and data expert contributors. We wish to express our most sincere appreciation to the institutions and teams that supported this project as well as all the projects that have made EMODnet possible. Your guidance and belief in our vision were fundamental for the outcomes achieved and motivating our large team to work together towards common goals.

The European Marine Observation and Data Network (EMODnet) is financed by the European Union under Regulation (EU) No 508/2014 of the European Parliament and of the Council of 15 May 2014 on the European Maritime and Fisheries Fund.

The EC, by means of the European Climate, Infrastructure and Environment Executive Agency (CINEA) funds the current EMODnet Data Ingestion project.

For what is concerning the data, we want to thank the Transpobank s.r.l. for their assistance in the experiment about underwater noise data, for the citizen science data, the MedShark association, the ENEA team, and the University of Rome "La Sapienza" for their willingness to share data. Regarding the MedFever project, we express our gratitude to the LUSH Italia for the financial support and Mireno Borghini (CNR) for the calibration facility.

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MONITORING THE PHENOMENON OF SEAWATER INTRUSION IN THE ESTUARY AREA OF THE RIVER MAGRA AND IN THE ALLUVIAL PLAIN OF THE LOWER VAL DI MAGRA (SP)

Marco Sabattini, Francesco Ronchetti, Diego Arosio, Gianpiero Brozzo, Andrea Panzani

Abstract: Seawater Intrusion (SI) is a critical problem as a consequence of climate change. The progression of the salt wedge inland compromises the quality and quantity of groundwater, seriously damaging agriculture and gradually desertifying the territory. The alluvial aquifer of the Lower Val Magra (LVM) is one of the most important in Liguria (Italy). It supplies drinking water to the city of La Spezia. The main objective of this research is to determine the severity of the SI phenomenon in the LVM aquifer and in the River Magra estuary. Data from different databases (ACAM, Aral, Ispra) and new original data were used for this purpose. The analytical methods focused on multivariate statistics (HAC, PCA and PLS). It was found that the migration pattern of SI along the estuary is mainly controlled by river discharge and wind speed. The weir in Romito (8.5 km from the sea coast) is the current limit of the SI in the R. Magra. About the groundwater, the most salinized wells are concentrated in the Marinella plain. For the other part of the LVM, aquifer water quality is good, but will be deteriorate in the next years as a consequence of climate change.

Keywords: Seawater, Groundwater, Isotopes, Estuary, Monitoring

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Marco Sabattini, Francesco Ronchetti, Diego Arosio, Gianpiero Brozzo, Andrea Panzani, *Monitoring the phenomenon of seawater intrusion in the estuary area of the river Magra and in the alluvial plain of the lower Val di Magra (SP)*, pp. 999-1010, DOI: 10.36253/979-12-215-0556-6.87

Introduction and test site setting

Seawater intrusion (SI) in the Mediterranean area is a critical problem. Population growth and climate change increasingly expose coastal aquifers to salinization. The progressive intrusion of the salt wedge inland causes soil salinization, reducing soil permeability and severely damaging agriculture. This process impoverishes ecosystems, particularly in terms of plant species biodiversity, and ultimately leads to the desertification of the territory, with severe environmental, health, and economic consequences.

Liguria (Italy) is a region on the Tyrrhenian Sea coast. It is a hilly territory where alluvial plains are few, of limited extension and often densely populated. The aquifers in these flood plains are frequently of limited thickness (a few tens of metres).

The alluvial aquifer of the Lower Val Magra (LVM) (Figure 1) is one of the most important in the region. It supplies drinking water to the city of La Spezia and numerous municipalities in the area. The LVM is highly urbanised, industrialised and has extensive agricultural areas. The main features of the LVM aquifer are listed in Table 1 [1, 2, 11].

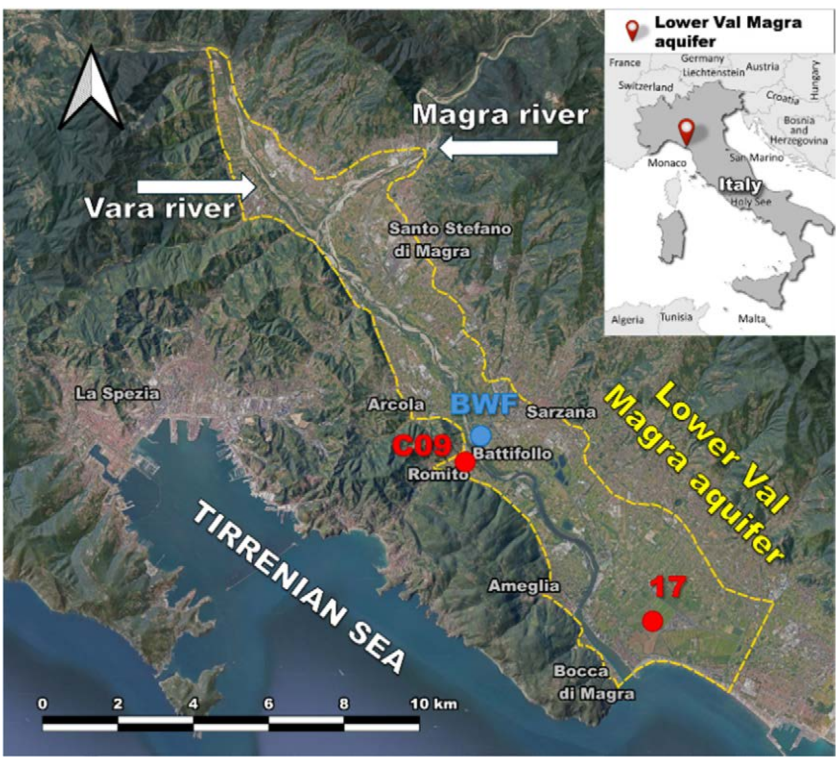

Figure 1 – Location and map of the research area and boundaries of the LVM aquifer. In red are represented the wells (C09 and 17) where the SI was detected. In blue is displayed the position of the Battifollo aqueduct Well Field (BWF).

The Lower Val Magra region experiences both tectonic and sedimentary subsidence due to its graben structure. Tectonic downwarping has led to the accumulation of a thick sediment layer, forming the current alluvial deposit. This subsidence is more intense downstream of the Romito-Sarzana line, where a transverse fault disrupts the graben's continuity. South of Sarzana, where subsidence is greater, the sediment deposit exceeds 50 meters in thickness. This downwarping has historically created favorable conditions for transitional environments such as marshes, coastal lagoons, and bays [1, 2, 11].

Tectonic and sedimentary subsidence, along with recent sea level rise due to climate change, are increasing the intensity and accelerating the process of SI in the region. The estuarine morphology of the Magra River, the main source of aquifer recharge, serves as a preferential pathway for SI into inland areas [16]. The combination of these predisposing factors and the site's high significance makes seawater intrusion a tangible risk for the region.

Table 1 – Summarises the main characteristics of the LVM aquifer and its boundary.

Aquifer features
Unconfined
Water table closes the ground level (3-7 m depth)
Single-layer/multi-layer (towards the sea)
Aquifer texture: coarse deposits (high permeability)
Aquifer recharge by: river, rainfall and irrigations
SI is the main cause of water quality degradation in the area
Land use: urban area, industrial area, agricultural area

Recent monitoring of groundwater electrical conductivity (EC) in several wells has revealed rapid salinization related to SI phenomena, extending from the seacoast up to 8 km inland (Figure 2). The proximity of the CO9 well in Romito, which is periodically affected by these phenomena, to the Battifollo aqueduct Well Field (BWF) (Figure 1) has necessitated further investigation into SI in the Lower Val Magra (LVM) to protect the fresh groundwater resource.

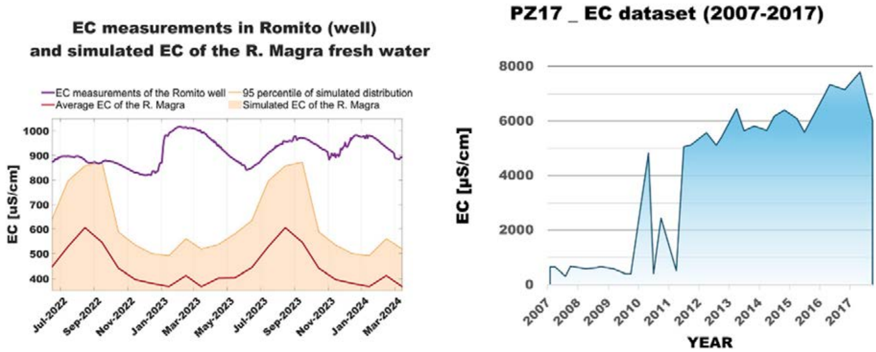

Figure 2 – Left: EC signal (continuous monitoring) of groundwater at well C09 in Romito (8 km from the sea coast) and comparison with freshwater EC values of the R. Magra. Right: EC signal (periodic monitoring) of groundwater at well 17 (1.2 km from the sea coast).

In order to protect people's health and to preserve BWF, this research has the following objectives:

- To update knowledge on SI in the LVM plain with a focus on the R. Magra estuary
- Conceptually define the saltwater migration process along the estuary
- Hydrochemical exploration of the floodplain to identify aquifer recharge areas
- Identify areas of the aquifer potentially exposed to SI
- Investigate salinisation dynamics of wells

Materials and Methods

The research was organised into 2 macro-themes:

1. R. Magra and surface water monitoring. For this purpose, 14 strategic monitoring points were identified along the R. Magra and in its estuary (Figure 3). At these stations, every 2 months, EC measurements of surface water were performed and samples were collected. The water samples were analysed using Isotope Ratio Mass Spectrometry (IRMS ISO) to measure the environmental tracer $\delta^{18}O$ [12]. Estuaries are highly dynamic systems governed by the interactions of tides, river flows and coastal currents [3, 16, 17]. Partial least square (PLS) regression technique was applied to model the data measured at the stations using the main environmental variables. The environmental variables considered in the model are: river discharge, tidal oscillations and wind direction and speed. These data come from the Arpal and Ispra databases.
2. Groundwater monitoring. For the objectives, a robust dataset was created by including hydrochemical data (major elements, trace elements and physical parameters) from 45 wells in the LVM (ACAM and Arpal sources) (Figure 3). The dataset was processed using multivariate analysis techniques: hierarchical cluster analysis (HCA) and principal component analysis (PCA) [6].

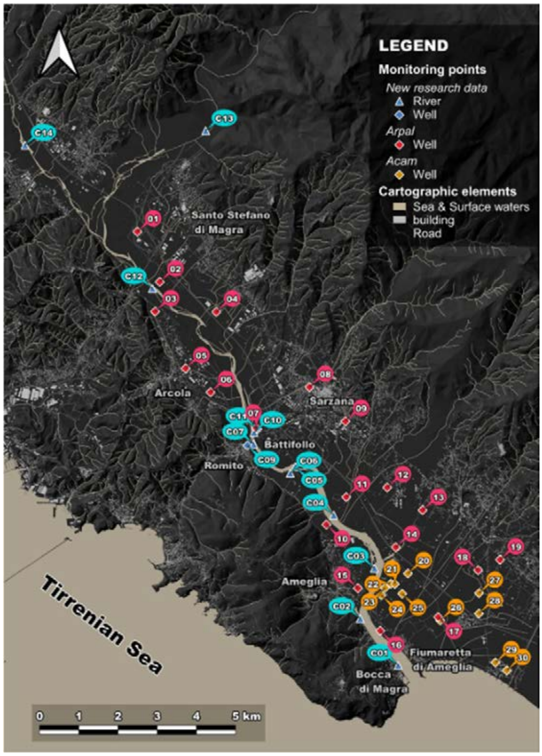

Figure 3 – Map displaying the location of the monitoring points. For some points the data come from databases published by other institutions (Arpal, ACAM), for other points new sampling was carried out (new research data).

Results

During the research years (2022 and 2023), a meteorological condition of intense and protracted drought was observed.

The Standard Precipitation Index (SPI) was used to quantify the magnitude of the drought phenomenon [10, 18, 19]. Data from the Sarzana weather station are used for the calculation. The station has an important historical record, with cumulated rainfall data from 1932 to the present.

Figure 4 shows as a matrix the SPI value for the years 2008-2023 (columns) calculated with aggregations of 3, 6, 12 and 24 months (rows). The chosen aggregation times provide information on the possible effects of drought in the short and long term [9, 10, 13, 15, 18, 19].

In the period 2022-2023, the index values (reaching -3) show severe (< -1.5) and extreme (< -2.0) drought conditions for all aggregation periods considered. This suggests probable negative effects on soil moisture, river discharge and aquifer recharge [9, 10, 13, 15, 18, 19].

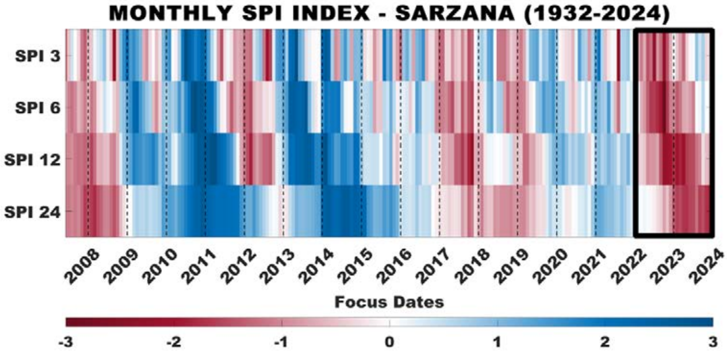

Figure 4 – SPI index matrix calculated for the Sarzana station. In the black rectangle is highlighted the research period.

During the same period, surface water EC values were measured periodically during 6 measurement campaigns involving all monitoring stations on the R. Magra. The collected data were reported in maps showing time-lapse images of the SI pattern along the estuary. SI pattern are the result of different climatic conditions and seasonality and summarise the dynamism of the estuary area.

The two extreme situations observed are shown in Figure 5: at left the EC pattern representing the minimum SI and at right the EC pattern representing the maximum SI along the R. Magra. The maximum observed SI reaches the natural weir located at the Romito toponym, 8.5 km from the mouth.

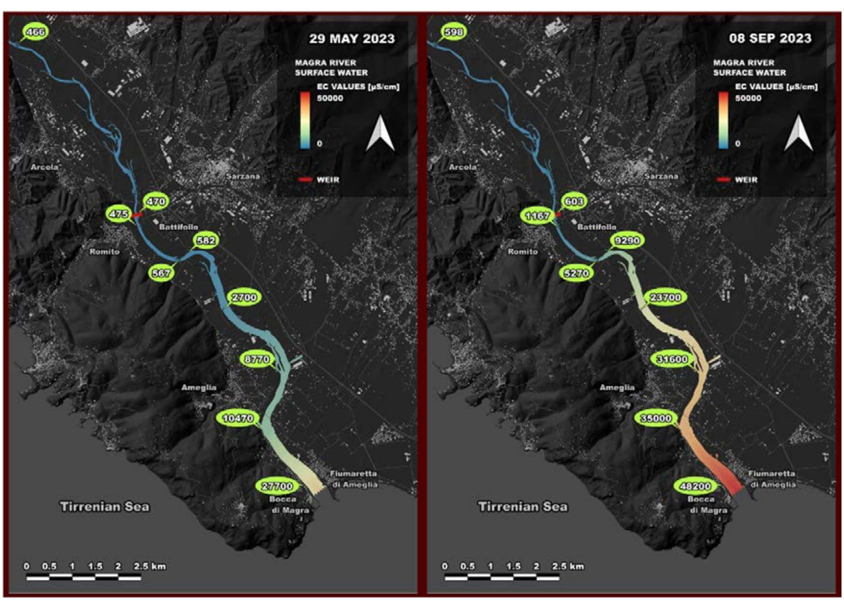

Figure 5 – At left: EC pattern representing the minimum SI observed along the R. Magra estuary. At right: EC pattern representing the maximum SI observed along the R. Magra estuary.

Regarding surface water isotopic monitoring, the graph in Figure 6 shows the EC- $\delta^{18}O$ pairs of all the monitoring stations downstream of the Magra-Vara confluence during all the measurement campaigns. For the stations located in the estuary area (C01-C07), the graph shows a clear linear correlation between the two parameters (R2 = 0.99). This correlation is the result of the freshwater-saltwater mixing that changes in time and space, from Bocca di Magra to Romito, as a consequence of winds, tides and river discharge.

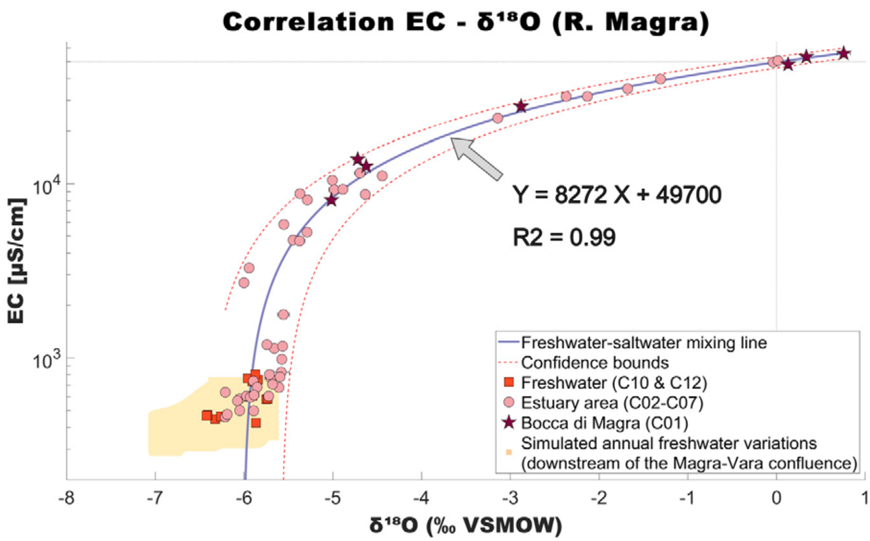

Figure 6 – EC- $\delta^{18}O$ bi-variate plot for all R Magra surface water samples collected.

The application of the HCA to the LVM groundwater hydrochemical dataset permitted the definition of 5 clusters. The map (Figure 7) shows the spatial distribution of the 5 clusters. Voronoi polygons are used for the spatial transposition of the data obtained. A difference in groundwater chemistry between the wells upstream and downstream of Battifollo is evident.

Finally, the map in Figure 7 shows the groundwater EC values measured in the wells. The map indicates that wells near the estuarine area have above-average EC, with the highest values located in the Marinella plain, north of Fiumaretta.

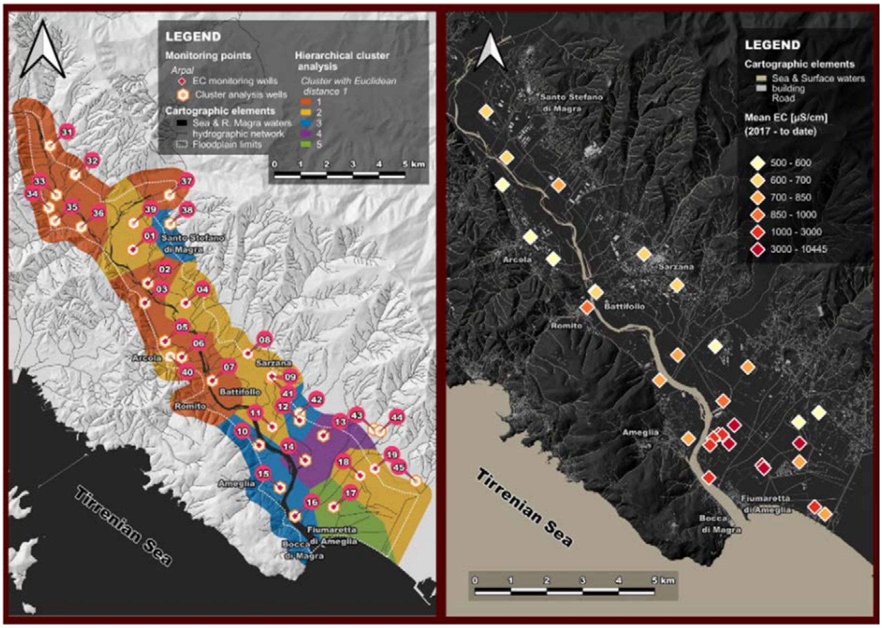

Figure 7 – At left: map showing the spatial distribution of the 5 clusters obtained through HCA. At right: map of groundwater EC values measured in wells (EC value: average from 2017 to date).

Discussion

The distribution maps of electrical conductivity (EC) in surface waters (Figure 5) show constant values upstream of the natural weir at Romito, while downstream, the EC values progressively increase due to the presence of seawater. The weir creates a higher hydrometric level upstream, forming a natural barrier for SI in surface waters. During the investigations, the weir marked the limit of SI along the R. Magra, 8.5 km from the coast.

The natural weir at Romito is the only altimetric protection for the BWF. However, future sea level rise scenarios, published by NASA and corresponding to global eustatic variations, indicate that the weir will be insufficient to contain SI along the R. Magra. (Figure 8) [4, 5, 7]. These scenarios become even more critical considering the ongoing tectonic and sedimentary subsidence in the area.

A strong correlation between EC and $\delta^{18}O$ was obtained in surface waters in the estuarine area. This suggests that both parameters can be used as predictors of freshwater-saltwater mixing and consequently to monitor the SI. This is true for surface water as well as groundwater (Figure 9).

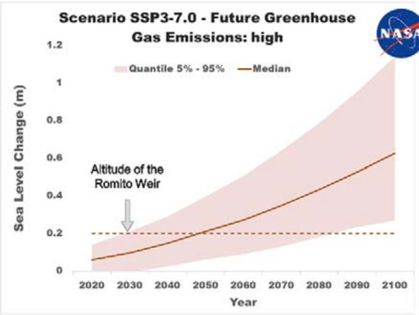

Figure 8 – At left: sea level rise scenario (NASA) and comparison with the altitude of Romito Weir. At right: photo of Romito Weir.

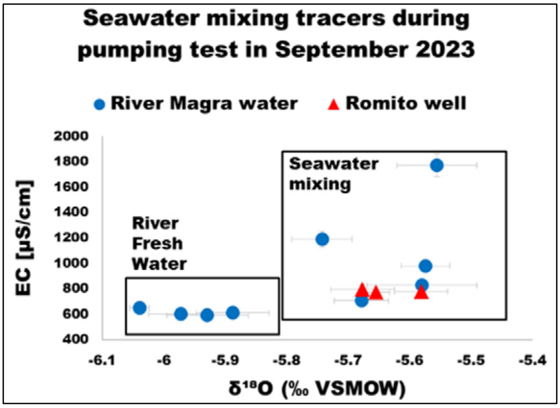

Figure 9 – Application of the EC- $\delta^{18}O$ pair to identify SI in groundwater in the Romito well. The EC- $\delta^{18}O$ values of the groundwater are compared with the values measured in the surface waters of the R. Magra in the same days and representing freshwater-saltwater mixing.

$\delta^{18}O$ is calculated from stable isotopes of the water molecule. This means they are little affected by factors such as the presence of pollutants. This characteristic is among the advantages of $\delta^{18}O$ over EC and for this reason $\delta^{18}O$ was chosen in this research as the target for PLS.

PLS was applied to investigate the effects of some environmental factors (river discharge, tidal oscillations and wind direction and speed) on the SI migration in the surface waters of the R. Magra. The multivariate regression model suggests that discharge and wind speed are the main factors controlling the pattern of SI along the estuary. The dominant winds from the sea to the inland (Figure 10) and the low river discharge are the main predisposing factor for SI. In contrast, tidal fluctuations are less relevant and only contribute at the extremes of the estuary area (C01, C06 and C07).

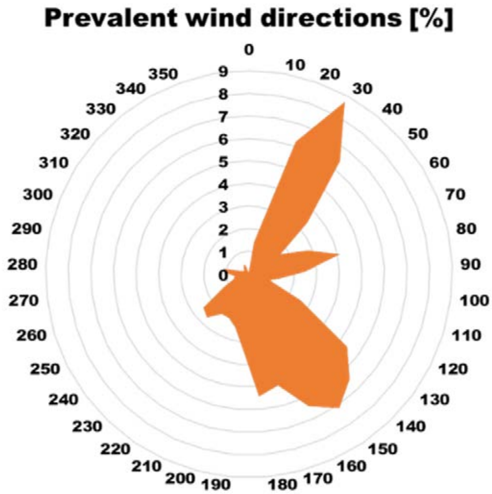

Figure 10 – Direction of dominant winds from 2010 to date in the study area (La Spezia tide gauge).

HCA was applied for the exploration of the groundwater hydrochemistry dataset (major elements, trace elements and physical parameters). The HCA distinguished five main clusters. PCA on the same dataset identified the characteristics describing these clusters and suggest a possible interpretation:

- Cluster 1 - low-salt waters directly connected to the R. Magra;
- Cluster 2 - waters with a higher salt content than Cluster 1, but still connected to the waters of the R. Magra;
- Cluster 3 - waters chemically different from the first two clusters and related to streams coming from the valley slopes;
- Cluster 4 - waters with a high carbonate content and related to streams coming from the valley slopes;
- Cluster 5 - waters with a high salt content, especially chlorides, resulting from mixing with seawater.

The HCA shows a clear hydrochemical distinction in groundwater between the wells upstream and downstream of the natural Romito weir.

Moreover, the HCA supports the hypothesis developed by some authors that the alluvial deposit downstream of Battifollo is not gravelly-sandy but is predominantly pelitic [11]. According to this hypothesis, towards the sea the aquifer became multi-layer. The most superficial layer is associated to the presence in the fine deposit of sandy cords (old seacost) and of the ancient river system of the Magra (Roman age). The EC values of the groundwater support this hypothesis and suggest a relationship between these ancient environments and the SI in the Marinella plain.

Conclusion

The research was conducted during an intense and anomaly drought period that characterized all the Mediterranean area in the years 2022-2023. Climate change may favour these periods of extreme drought with increasing frequency and severity. This drought phenomenon can facilitate SI and compromise the quality of superficial water and groundwater in the coastal area.

In our test site, about superficial water, results highlighted as the migration of salt water along the estuary of the R. Magra is mainly controlled by river discharge and wind speed. The natural weir in Romito (8.5 km from the sea coast) is the current limit of the SI and the only protection of the BWF. Future scenarios of relative sea level rise (resulting from subsidence and climate change) could soon invalidate this natural protection for the BVF [4, 5, 7].

Nowadays, about the groundwater, the most salinized wells are concentrated in the Marinella plain. There is probably a relation between their spatial distribution and the ancient Magra river system and sea coast line. For the other part of the LVM, aquifer water quality is good, but will be deteriorate in the next years. According this risk, the main suggestions that the research recommended are:

- Implementation of a continuous monitoring network (EC) for the aquifer in the LVM, and in particular in the Marinella plain and in the BVF area.
- Design of a new weir where the Romito natural weir is localized.

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THE SEA LEVEL RISE OF THE NEXT HUNDRED YEARS. THE CASE STUDY OF MIAMI AS A PARADIGMATIC EXAMPLE FOR MEDITERRANEAN COASTS

Chiara Simoncini

Abstract: The climate crisis demands urgent strategies to stabilize our settlements and improve city sustainability. This challenge, especially in rapidly changing areas, has driven research to develop precise monitoring and analysis tools. In Miami-Dade County, sea levels have risen by 30 cm since the early 1900s, surpassing the global average. *King tides* are now four times more frequent than 15 years ago. Predictions for sea level rise by the end of the century suggest an increase of 1.5 meters for the U.S. eastern coast. If this happens Southern Florida will become uninhabitable. The county's protection plan involves increasing residential density in low-value neighborhoods, primarily inhabited by low-income families and minorities, risking "climate gentrification." This could displace current residents due to rising costs, altering urban identity and demographics. These issues, though less familiar to the Mediterranean, are increasingly relevant as *medicanes* cause growing damage. The Miami case study's analysis, based on IPCC and NOAA forecasts, provides crucial data for designing coastal protection systems and preventing similar social issues in other country.

Keywords: Medicanes, Flooding, Sea level rise, Climate Change

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Chiara Simoncini, *The sea level rise of the next hundred years. The case study of Miami as a paradigmatic example for Mediterranean coasts*, pp. 1011-1018, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.88

Introduction

The contemporary interpretation of the Mediterranean as an economic, social, and political unit/multiplicity involves a long-term examination of human interactions with the spaces that have always defined it. The coastal zone, historically a site of significant transformations, has now become a stage for current major changes, driven not by large-scale mercantile exchanges but by catastrophic climatic events. These events have made it increasingly urgent to formulate hypotheses that might allow us to continue living in the world we know, by halting ongoing events or, optimistically, improving the condition of our cities and, consequently, our lives, thus enabling us to become actors in a potentially sustainable system.

This challenge, in certain areas experiencing more rapid and sudden climatic changes, has spurred research to identify emerging practical applications, allowing for more precise monitoring and analysis of marine dynamics. For example, in South Florida, particularly Miami-Dade County, sea levels have risen by 30 cm since the early 1900s and over 10 cm since 1993, at a much faster rate than the rest of the planet. Experts project a significant rise of approximately 1.5 to 2 meters by the end of the century. If this scenario becomes reality, nearly one-third of present-day South Florida will become uninhabitable due to sea-level rise.

Methods

Miami is currently experiencing a projected future of a catastrophic reality that the entire Mediterranean basin will have to confront in the near future. Although it is a location subjected to different climatic pressures, and although it involves oceanic dynamics rather than Mediterranean ones, characterized by a much more rapid temporal scale and a higher level of catastrophic assessment, it is becoming a Mediterranean issue as well.

The evaluation of this case study is based on a review of the existing scientific literature and on empirical data collected through in-situ survey instruments in Miami and several Mediterranean coastal locations. Through a multidisciplinary approach, it was possible to examine sea level rise in Miami and the potential implications for Mediterranean coasts. The methodology was structured into four main phases: collection and analysis of historical data and future projections, assessment of socio-economic impact through qualitative and quantitative methods, examination of adaptation strategies, and study of comparative cases.

Historical Data and Future Projections: Using data provided by the National Oceanic and Atmospheric Administration (NOAA) and the Intergovernmental Panel on Climate Change (IPCC) [fig.1], we charted historical sea level trends for Miami-Dade County and several Mediterranean coastal areas characterized by different coastal types: sandy or rocky seabeds, sandy or rocky shorelines. Utilizing advanced climate models, we extrapolated sea level rise projections up to 2100, considering different greenhouse gas emission scenarios (RCP2.6, RCP4.5, RCP8.5).

- *Economic Impact*: Identifying critical infrastructures essential for community life allowed us to determine the potential economic loss if sea level rise rendered these infrastructures unusable, thereby causing significant disruptions to community life.
- *Social Impact*: The evolution of this environmental dynamic is effectively transforming the determination of safe areas, leading to large-scale population migration. Surveys and interviews with residents and local authorities were conducted to assess the perception of risk regarding these issues.
- *Adaptation Strategies*: We examined the measures adopted by Miami-Dade County authorities to counteract sea level rise and evaluated their applicability to Mediterranean coasts, considering environmental, economic, and cultural differences.

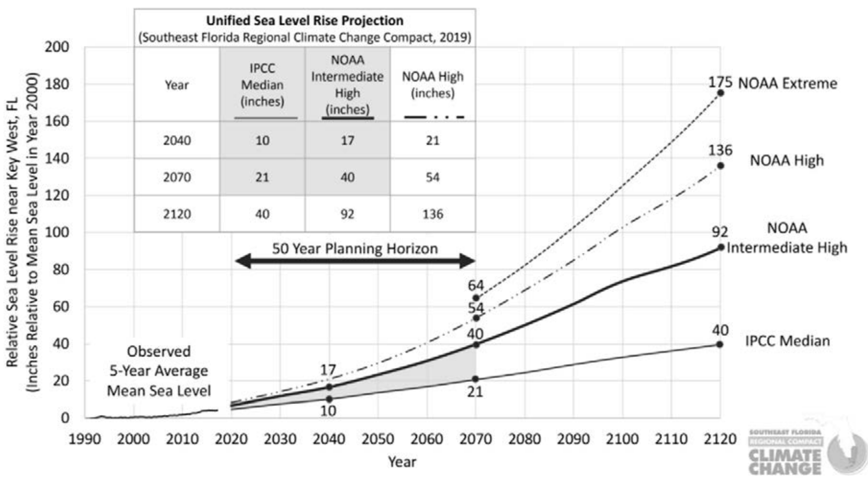

Figure 1 – Unified Sea Level Rise Projection, Southeast Florida Regional Climate Change Compact, 2019.

The latest updated (2019) “Unified Sea Level-Rise Projection” presented by the Southeast Florida Climate Change Compact partnership incorporates sea-level rise estimations from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (IPCC, 2014) and projections from the National Oceanic and Atmospheric Administration (NOAA) (Sweet et al., 2017). These projections (Figure 1) served as the foundation for the development of this study.

Projected sea-level rise, especially beyond 2070, exhibits a significant range of variation due to uncertainties in future greenhouse gas emission reduction efforts and the decisions and investments communities will make to enhance their climate resilience. It is important to note that these models are rapidly evolving and depend on numerous key factors. The NOAA Extreme model is included in this study to illustrate potential outcomes if carbon emissions continue to rise unchecked and account for the rapid degradation of ice sheets in polar regions. Including extreme scenarios is a common practice, as seen in California's H++ scenario, referenced in the Unified Sea Level Rise Projection Report. The reported data do not account for the process of subsidence but exclusively consider the eustatic process, focusing solely on absolute sea level rise rather than relative variation.

Observing the average sea-level rise alone does not fully capture the potential damages, as tidal variations also significantly contribute to inundation. To provide a more comprehensive prediction of the financial and social impacts on Miami, this study has also considered the effects of tidal cycles, which cause short-term sea-level fluctuations and can lead to temporary inundation of areas that would otherwise remain dry if only the average sea level was considered.

To better understand the potential magnitude of these events, the mean higher high water (MHHW) level at the Miami Biscayne Station [fig.2], which represents the average height of the highest tide recorded each day during the recording period, has been analyzed and incorporated into each sea-level rise prediction discussed.

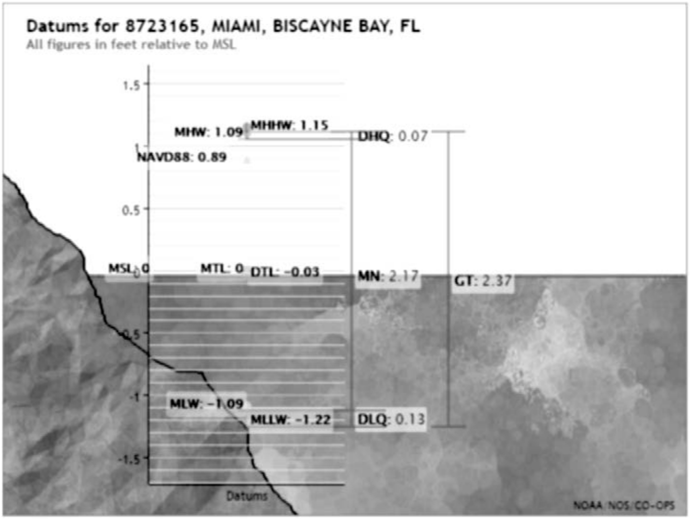

Figure 2 – Datums for Miami Biscayne Bay Station (relative to MSL), Florida.

Results

The data for this project was primarily sourced from three repositories: the Miami-Dade County Open Data Hub, ArcGIS Business Analyst, and the NOAA Tides and Currents Database [fig.3].

A geographic information system (GIS) connects data to maps, enabling the creation, management, and analysis of various types of information. GIS is a powerful tool that enhances communication, efficiency, management, and decision-making.

The analysis began with a 2018 Digital Elevation Model (DEM) created using Light Detection and Ranging (LIDAR) data for Miami-Dade County. This DEM has a horizontal resolution of 5 feet, meaning that all LIDAR data points within each 5-foot by 5-foot area were averaged to a single representative point for that area.

Additional layers were imported from the MDC Open Data Hub, including line layers representing streets, polygon layers representing parcels, and point layers containing property valuations. These layers are essential for conducting financial evaluations [fig.4, fig. 5].

Understanding community vulnerabilities and capacities is crucial to estimating the social impact of sea-level rise and flooding on the city. To assess these impacts, eight key infrastructures were selected based on their importance and the magnitude of disruption their inaccessibility would cause:

- Educational Buildings
- Electricity Generation
- Fire Departments
- Food Supply
- Government Offices
- Healthcare Services
- Police Departments
- Water/Wastewater Systems

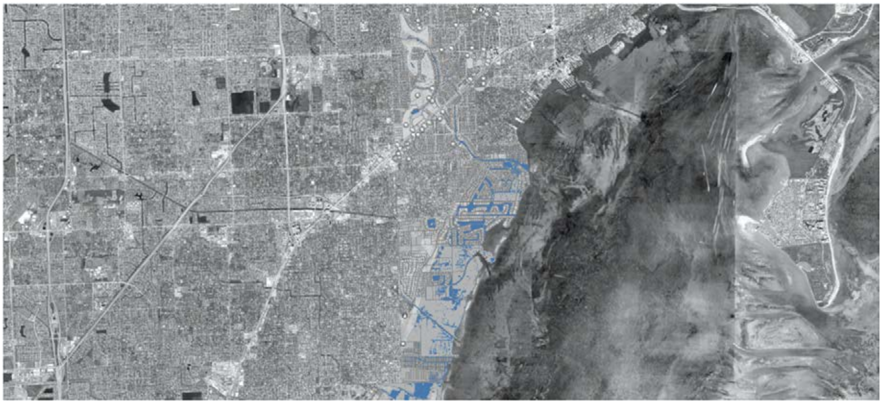

Figure 3 – Miami 2022.

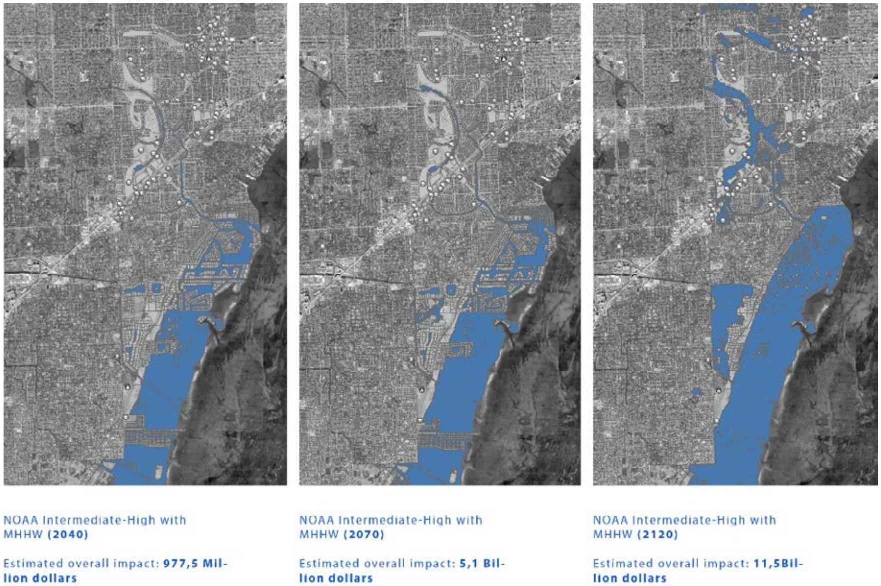

Figure 4 - NOAA Intermediate-High with MHHW in 2040, 2070, 2120.

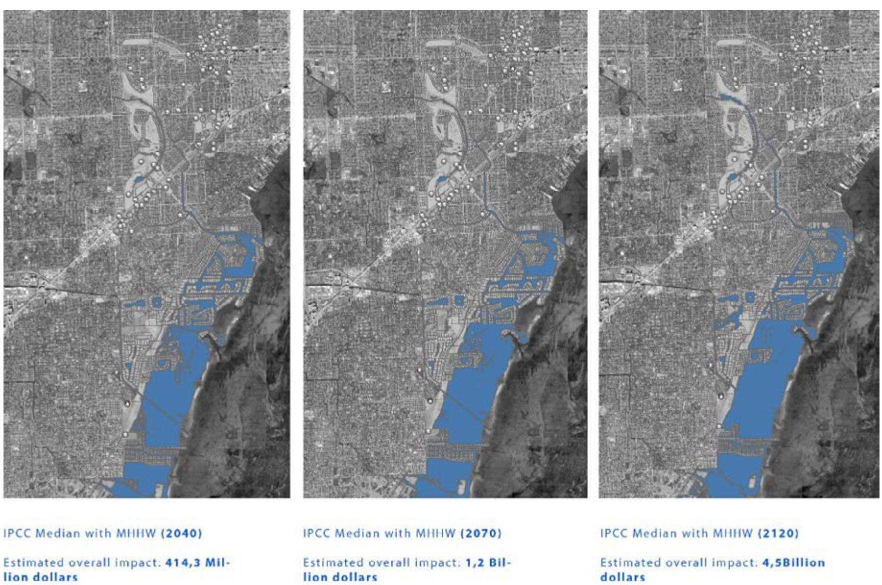

Figure 5 – IPCC Median with MHHW in 2040, 2070, 2120.

This investigation allows us to establish a general overview of what the situation might be for the eastern Florida coast, particularly in Miami-Dade County, in the absence of any protective strategies.

In response to this emergency, we explored the strategies adopted by Florida authorities to adapt to such changes and evaluated their applicability to Mediterranean coasts.

- *Literature Review*: We examined scientific literature and government reports on the adaptation measures implemented in Miami, including engineering projects, urban policies, and water management techniques.
- Comparative Analysis: We compared Miami's strategies with those adopted in similar Mediterranean locations, assessing the feasibility and effectiveness of various adaptation measures.
- *Adaptability Assessment*: We analyzed the geographical, climatic, and economic differences between Miami and Mediterranean coasts to determine how Miami's strategies could be modified and adapted to the Mediterranean context.

Government authorities have currently proposed implementing a series of land protection plans that hypothesize increasing residential density in areas further from the coast. These areas are traditionally characterized by low property values and a predominance of low-income families, many of whom belong to ethnic, religious, or linguistic minorities.

This strategy, by not addressing the resolution of the catastrophic scenarios predicted by climate trends, has inadvertently caused a series of unexpected social effects: the territorial neo-colonization by the wealthier class is effectively leading to the ghettoization of the less affluent classes, who are forced to relocate, resulting in permanent alterations to the urban, social, and territorial identity.

These environmental, urban, social, territorial, and especially maritime issues are increasingly highlighting the need to develop project hypotheses capable of addressing the crisis affecting the entire territory of Florida. This serves as a paradigmatic case of an oceanic dynamic that, although characterized by a much faster temporal scale and a higher level of catastrophic assessment, is also becoming a Mediterranean issue.

Conclusion

The new catastrophic climatic dynamics, including torrential rains and increasingly frequent Mediterranean hurricanes, have established a line of similarity with the American reality, which is currently experiencing a projection of the future scenario for our seas. This provides us with more time for reflection, a period in which action is still possible, and where architecture, as a tool for territorial requalification, remains a plausible means of resolution. Architecture is capable of safeguarding the territory, the landscape, and, therefore, the entire system of the most vulnerable areas that dot the Mediterranean.

The Mediterranean coasts, hosting numerous urban centers and crucial economic activities such as tourism, are equally vulnerable. Beach erosion, groundwater salinization, and the increase in storm surges present concrete threats to the economy and quality of life.

Miami can thus become a paradigmatic case for the development of adaptation measures, including:

- Elevation of roads and infrastructure: Some roads have been elevated to prevent flooding.
- Water pumping systems: Pump systems have been installed to manage rainwater and floods.
- Storm surge barriers: Construction projects for barriers and levees are underway to protect the most vulnerable areas.

These strategies can be adapted to the Mediterranean coasts, with modifications to better align them with the local landscape and territorial systems.

- Local-scale engineering projects: Considering the different coastal morphology and available resources, solutions must be customized for each location.
- Strengthening existing infrastructure: Enhancing urban infrastructure to withstand flooding and erosion.
- Sustainable urban planning: Integrating adaptation measures into the master plan, encouraging the construction of resilient buildings and the use of sustainable materials.

To safeguard is to preserve the material and immaterial heritage that would be lost if the reality in which we live were to vanish. To safeguard is simultaneously to defend and to act in the redetermination of those fragile places.

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TOWARDS A GUIDE FOR BUILDING DIGITAL TWINS OF PORT INFRASTRUCTURE

Christina N. Tsaimou, Vasiliki K. Tsoukala

Abstract: Ports are critical infrastructure assets with a pivotal role in functional and spatial activities associated with maritime transportation. In an era of intense pressures on the digitalization of every part of the economy, building Digital Twins (DTs) of port systems has become increasingly important aiming at solving problems before they occur. Although port DTs are mostly used for logistics and operational purposes, DT technologies can also support lifetime performance management of port infrastructure by investigating the in-service structures' behavior against potential degradation threats. To this end, the present work conceptualizes a guide for building DTs of port infrastructure based on Structural Health Monitoring (SHM) applications. The guide includes sensors mounted on Unmanned Aerial Vehicles, Geographic Information Systems tools, automation techniques, and structural condition assessments combined to assist in computer-aided twinning. To examine the effectiveness of the guide, a pilot DT was applied for the waterfront facilities of a Greek port, namely Lavrio port. The real-time replicas proved promising in searching for smart maintenance actions.

Keywords: Port infrastructure, Digital Twins (DTs), Structural Health Monitoring (SHM), Unmanned Aerial Vehicles (UAVs), Geographic Information Systems (GIS)

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Introduction

Ports, as complex networks that facilitate the transition of passengers and goods, hold a pivotal position in economic expansion by creating employment opportunities, providing income for workers engaged in port-related tasks, and boosting the economic prosperity of port-based areas through added value and logistics activities [13]. With the ever-increasing focus on advancing efforts toward sustainability and the high dependence of the global economy on maritime transportation, ports are challenged to enhance their performance with regard to operational, environmental, energy, safety, and security issues [14].

The competitive nature of maritime transportation forces ports to adopt innovative technologies to improve their performance, quality of services, and productivity [15]. Such innovations involve actions for conceptualizing and delivering smart ports [9, 14, 21], as well as for building Digital Twins (DTs) [10, 21]. Digital modeling of port systems assists in enhancing the asset's smartness [2] by constructing a digital replica with various technologies for visualizing and simulating the systems' behavior [10, 16]. These technologies may include state-of-the-art sensors for inspection purposes, artificial intelligence algorithms, and the Internet of Things (IoT) [2, 23].

Digital twinning is a constantly evolving trend. Digital models serve a variety of functions thus making it difficult to establish a unified definition and comprehension [10, 16]. Within the port industry, this challenge is further intensified by the complexity of port systems, the functionality of which relies upon the synergy of various actors in operations and processes. Hence, DT approaches for port systems are still in their infancy, requiring decentralized policies on managing targeted parts of port facilities and operations before proceeding with a systematic approach for port DTs. Considering this, port twinning has been expressed in terms of various aspects. Indicatively, DT technologies are applied to integrated port energy systems to achieve low-carbon development goals by combining full data coverage, low delay, reliable transmission, and real-time mapping of the physical system [24]. Advancements in port logistics include reliable predictions, autonomous distributions, and optimized container deployment by feeding digital replicas with operational and warehousing data [23]. Li et al. employed DT virtual sensing technologies to assist control issues in safety during construction [12].

Despite the ongoing research on port twinning, DT approaches for managing the lifetime performance of port infrastructure have not been yet explored. Ports are structural engineering systems with a variety of constructed structures [17] the integrity of which is affected by climate change challenges [11], exposure to natural hazards [5], adverse marine conditions, and anthropogenic actions [7]. To address such structural degradation-related issues and perform smart maintenance strategies, similar to other civil infrastructure systems, building a digital replica of a port structure can prove to be useful by forming a virtual representation continuously updated with Structural Health Monitoring (SHM) data [4]. SHM information is exceptionally useful for gaining a deep insight into the structural condition and behavior of a structure through intelligent inspections and structural state assessments [1]. Hence, SHM-based DT approaches may contribute to the optimization of maintenance costs and the on-time prediction of structural damages thus increasing the value of the infrastructure asset.

In light of the above, the present work conceptualizes a pilot guide for building DTs of port infrastructure by integrating SHM approaches with the ultimate goal of retaining functionality, ensuring sustainability, and increasing resilience. Technologies (e.g., remote sensing with Unmanned Aerial Vehicles, UAVs), tools (e.g., Geographic Information Systems, GIS), automation techniques (e.g., image processing of aerial imagery), and structural condition assessments are coupled together within the context of an SHM methodology to assist in computer-aided DT applications. To validate the robustness of the port DT guide, the structural twinning is applied at the mooring facilities and the windward breakwater of the domestic ferry and cruise domain of a Greek port. The overall investigation highlights the effectiveness of the proposed guide on modeling a DT for in-service port structures.

Materials and Methods

Digital Twins in Europe

The first appearance of DTs can be traced back to the early 00s when Grieves originated the concept within the context of Product Lifecycle Management [10, 16]. Since then DTs have gone far beyond PLM finding also applications in the port industry. DTs of port systems are popping up in European marine networks [10]. The port of Rotterdam in the Netherlands is developing a DT version that includes information about the port area such as infrastructure data, shipping movements, and environmental conditions aiming to construct a platform for optimizing mooring, loading, and departing (https://www.portofrotterdam.com/en/to-do-port/futureland/smart-shipping-process). The Digital Port Twin project related to the port of Hamburg in Germany targets to optimize control centers by digitizing infrastructure and analyzing sensor data (https://www.hamburg-port-authority.de/en/themenseiten/digital-testing-ground). Moreover, the Hamburg Port Authority initiated a project for building a DT for a bridge based on structural condition data acquired by monitoring sensors [22]. For the port of Livorno in Italy, a DT engine is fed with a pilot 5G network to navigate inside the digital replica through virtual reality applications [3]. One more port that leans to a digitalization mentality is the port of Gothenburg in Sweden [6]. Except for European ports, other ports worldwide have adopted the concept of twinning, such as the Ports of Shanghai and Dalian in China for the container terminals [16]. Despite the increasing popularity of port twinning, no attempts have been devoted to developing DT approaches for Lifecycle Management and Maintenance of port infrastructure. Therefore, in the following, a DT architecture is presented for port waterfront facilities built upon the engagement of SHM principles.

The SHM-based DT guide

The effective management of infrastructure assets recognizes the importance of SHM to ensure functionality and serviceability during their lifetime while assisting maintenance and repair decisions [1]. SHM applications are usually based on the employment of Non-Destructive Testing (NDT) sensors to acquire information about the structural condition of a structure and examine its structural behavior throughout its lifecycle. Current trends in SHM of port infrastructure include the employment of cameras mounted on UAVs [21]. The camera-based UAV applications improve the practicality of inspections and provide flexibility while reducing test duration, complexity of interpreting the results, and cost [18].

Complying with the core aspects of digital twinning included in [8] and summarized in [10] (a) identifying the *components* of the physical counterpart integrated into the twin, b) investigating the *temporal span* of the examined structures in terms of *complete lifecycle*, *changing requirements*, and *increased value over time*, and c) achieving the *functional scope* of a DT for *modeling*, *visualization*, *interaction*, and *synchronization*) the present research introduces a guide for SHM-based twinning focused on port waterfront facilities (e.g., concrete pavements of mooring facilities and rubble mound structures) by implementing the following three steps (Figure 1):

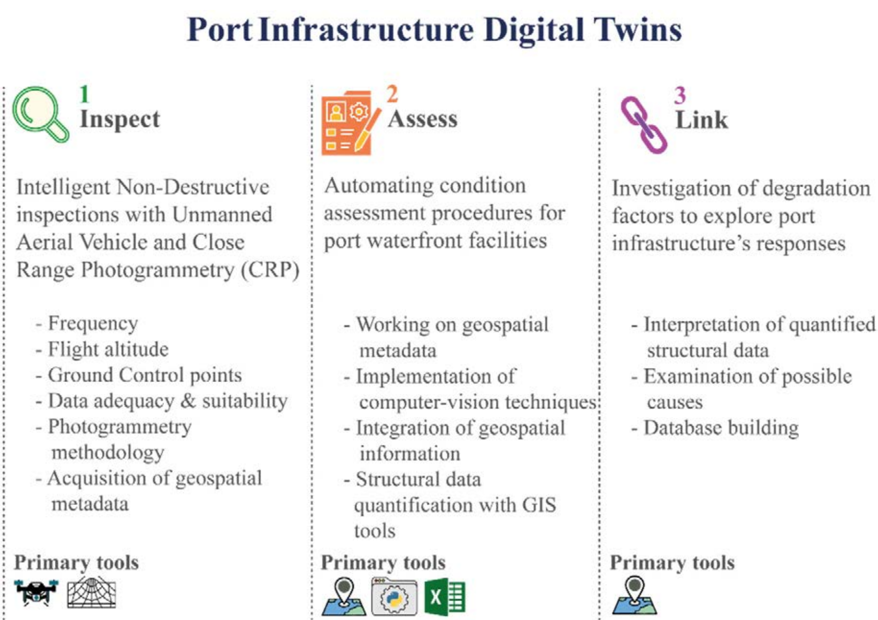

Figure 1 – The steps of a SHM-based DT guide for port waterfront facilities.

- Step 1: Implementation of periodic intelligent NDT inspections with UAVs equipped with high-resolution cameras and in-situ data analysis with Close Range Photogrammetry (CRP) for generating geospatial metadata (i.e., orthophotos and Digital Elevation Models, DEMs).
- Step 2: Automation in the structural condition assessment of in-service port concrete pavements and rubble mound structures. For the port concrete pavements computer vision techniques are employed to work with the geospatial data from Step 1 (i.e., CRP output) for crack detection with: a) modules imported in programming languages for managing georeferenced

images and b) GIS applications for analyzing geospatial metadata acquired by image analysis. Regarding the rubble mound structures SHM metadata acquired by analyzing UAV imagery (i.e., Step 1) are processed with GIS tools to investigate armor layer stability and develop an automated methodology to detect changes.

- Step 3: Change detection in structural integrity and investigation of degradation factors. The detected crack patterns are related to loading conditions from vehicles and other factors, while the detected instability issues are related to wave characteristics identified in between in-situ inspections. Linking structural defects and failures to potential causes assists in planning maintenance actions to address forthcoming damage evolution.

A detailed workflow of the processes required for the above steps is depicted in Figure 2. By following the DT architecture of Figure 2, the digital replicas of port waterfront facilities can be visualized and managed with GIS technology as proposed in similar work for digitizing the supply chain network in ports [23].

Results

The DT architecture depicted in Figure 2 was applied at a Greek port, namely Lavrio port, located in the southeastern tip of Attica. The specific port serves a wide variety of operations including domestic ferry, yacht, and cruise shipping, as well as commercial activities. The DT was initiated for the concrete pavements of the mooring facilities and the rubble mound structure of the domestic ferry and cruise domain. The intelligent UAV inspections were conducted on four discrete dates with different UAV flight altitudes (Table 1). Four orthophotos and four DEMs were generated with the Agisoft Metashape Professional software. The total duration of data collection and data analysis are included in Table 1.

Figure 3 shows an indicative example of the results of geospatially detecting a crack at the concrete pavements of the mooring facilities of the domestic ferry domain (Step 2 of Figure 1). Further details regarding the actions required for applying crack detection techniques for port concrete pavements through coding and GIS technologies can be found in [20]. Both the length and width of the detected crack can be quantified as shown in Figure 3 (images No. 9A and 9B). In this way, the DT engine of the port concrete slabs can be fed with crack characteristics. This information can be continuously updated with periodic inspections and included in GIS-based databases.

Table 1 – Summary table regarding the application of Step 1 of the port DT (Figure 1).

In-situ inspection No.	Date	Flight altitude (m)	Flight duration (min)	Duration of UAV data analysis (min)	Ground resolution (cm/pixel)
ISI-1	2020-02-10	48	20	48	1.06
ISI-2	2020-09-04	56	33	56	1.21
ISI-3	2021-02-10	76	13	76	1.66
ISI-4	2021-07-09	56	12	56	1.17

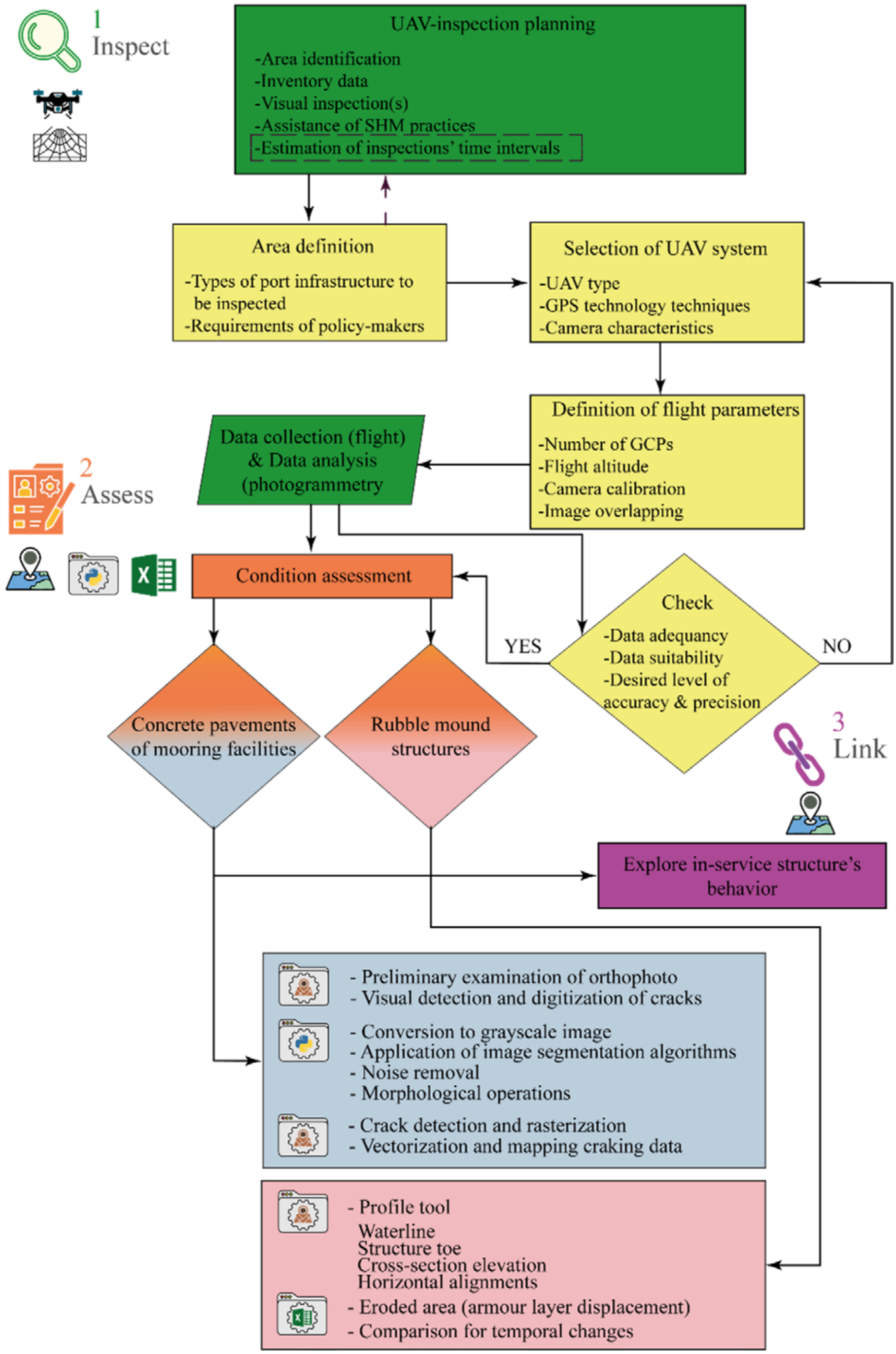

Figure 2 – The DT architecture for port waterfront facilities.

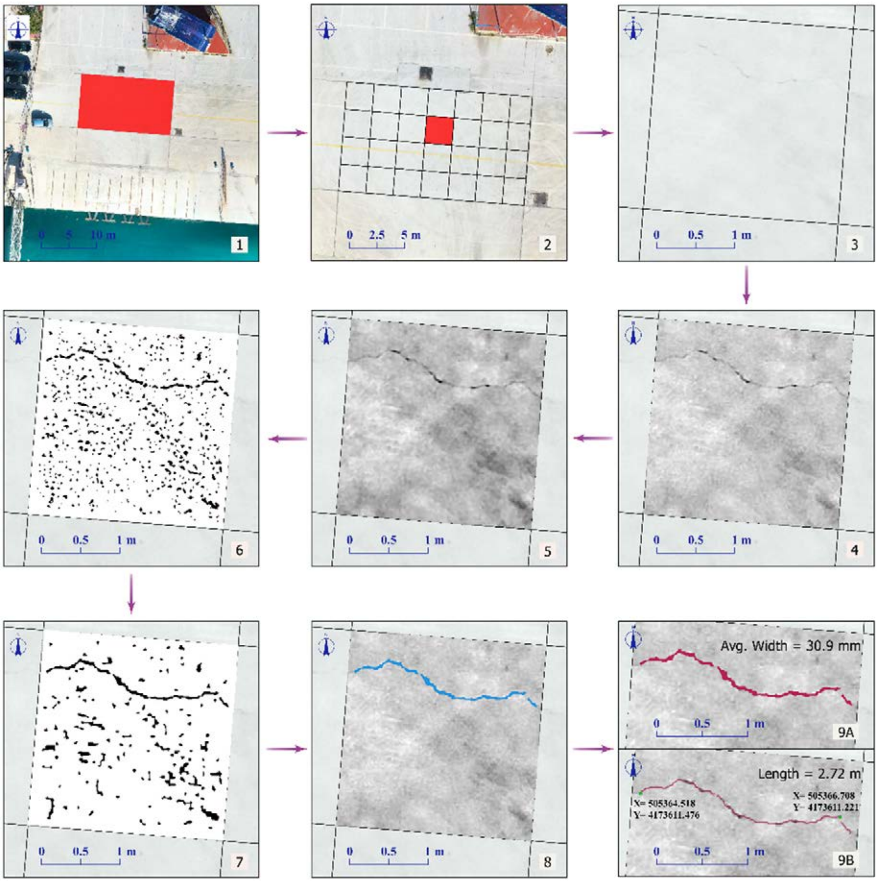

Figure 3 – Crack detection in a concrete slab of the mooring facilities of the domestic ferry domain in Lavrio port for ISI-1 [20]. Each image corresponds to the actions undertaken for automating crack detection processes including grayscale conversion of the Red Green Blue (RGB) orthophoto image (4), median filtering (5), image segmentation (6), morphological operations (7), and quantification of crack characteristics. The applied coordinate system is the Greek Geodetic Reference System 1987 (GGRS87).

Figure 4 illustrates the elevation changes in the armor layer of the considered rubble mound structure in Lavrio port. GIS techniques allowed for monitoring the displacements of the armor units and the increase in the eroded area between the time intervals of the in-situ inspections (Step 2 of Figure 1). The transverse cross-sections (profiles) were constructed along the examined structure as indicatively shown for sections 6 and 12 in Figure 4. Further details regarding the actions required to acquire this information are included in [19]. The DT engine is fed with cross-section details, thus assisting in monitoring the structural condition of the structure.

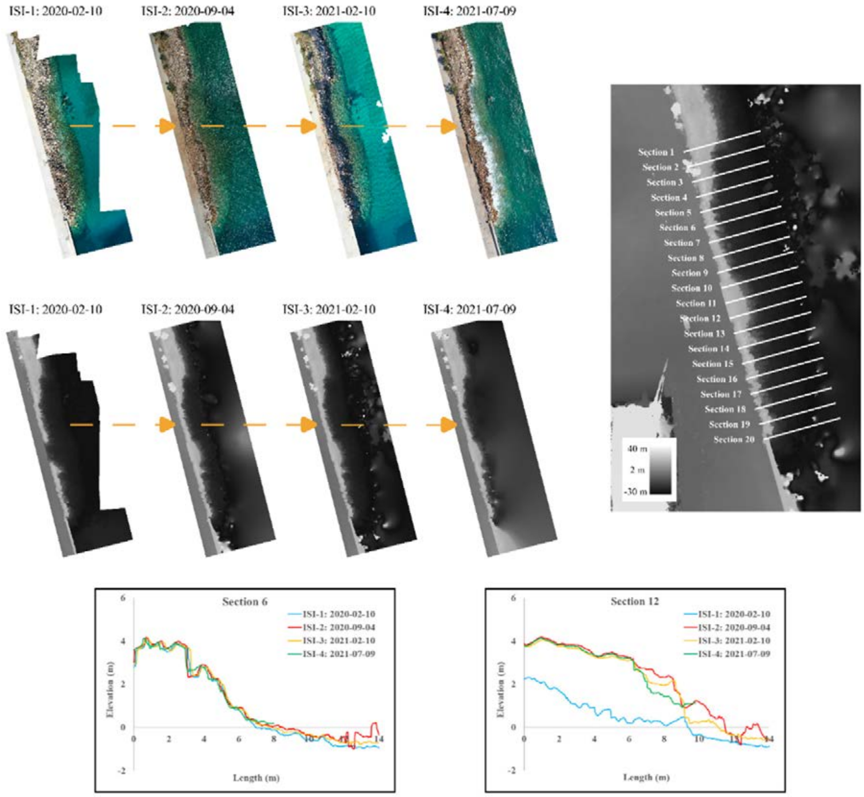

Figure 4 – Extracting information regarding armor units' displacement for the rubble mound structure of the domestic ferry and cruise domain in Lavrio port [19]. The elevation profiles were constructed based on the DEMs generated in Step 1 of Figure 1.

Discussion

Lifecycle Management and Maintenance of port infrastructure can be supported by i) comprehending the structural behavior and ii) modeling structural response against potential threats. The present work indicated that port SHM-based DTs allow for detecting and mapping structural defects of port concrete pavements and rubble mound structures by visualizing and digitally transforming the structural condition to geospatial output. Although the camera-based UAV technique employed herein for the SHM applications proved efficient in terms of condition assessment, the DT simulation for predicting and managing the structure's remaining lifetime requires further structural data. Indicatively, for the port concrete pavements of mooring facilities, the combination of UAV-acquired cracking data along with pavement thickness information from Ground Penetrating Radar (GPR) applications enables the development of simulation processes based on various loading scenarios (Figure 5a). Moreover, the integration of Remotely Operated Vehicles (ROVs) into unmanned intelligent inspections allows for constructing the entire rubble mound structure's profiles both above and under the waterline to examine the structural response against wave actions (Figure 5b).

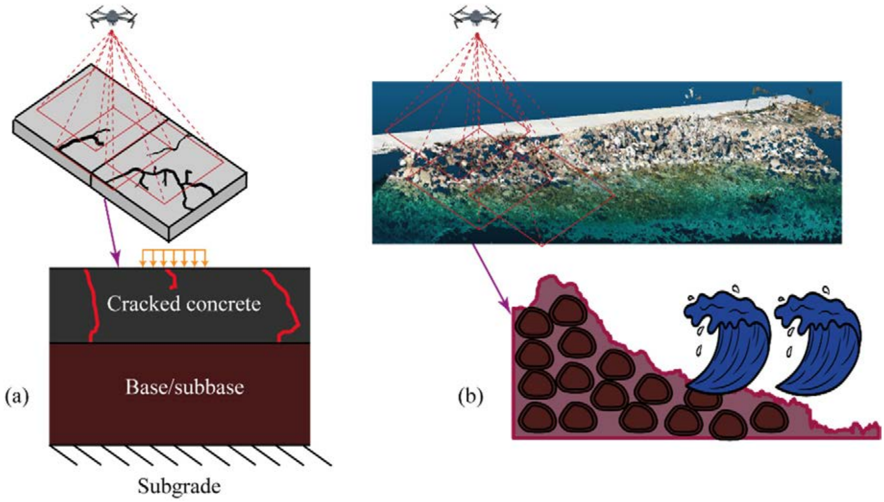

Figure 5 – Digital twinning for simulating the structural response of (a) port pavements with cracked concrete slabs against vehicle loads and (b) rubble mound structures under the influence of wave actions.

Conclusions

Digital Twinning of port systems can take many forms. Logistics, shipping operations, and security are among the most popular aspects of port DT. Within the context of Lifecycle Management and Maintenance of port infrastructure, the present paper seeks to feed a DT engine for port concrete pavements and rubble mound structures with SHM information. The contextualization of state-of-the-art remote sensing inspections, condition assessment methodologies, and GIS-based management of geospatial metadata supported the building of DTs. The periodic implementation of the UAV-based SHM program complied with the twinning aspect of temporal span by providing useful information for temporal structural changes and damage evolution in terms of defects, failures, and applied maintenance actions. Therefore, decision-making on applying smart maintenance practices can be supported.

Funding

The first author was supported for this research by the Special Account for Research Funding of the National Technical University of Athens, Greece (Scholarship grant number 65/219100).

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ADAPTATION OF THE COASTAL PROTECTION SYSTEM AT MARINA DI PISA, TO EXTREME SEA CONDITIONS: EXPERIMENTAL ANALYSIS OF THE SUBMERGED BREAKWATER AND GRAVEL BEACH

Amanda Zannella, Andrea Esposito, Irene Simonetti, Lorenzo Cappietti

Abstract: The coast of Marina di Pisa has been subjected to strong erosion for decades. The current protective system comprises a large rubble-mound seawall, 6 emerged rubble-mound breakwaters, and 4 cells made up of a submerged breakwater and an artificial gravel beach framed by two groynes at the extremities. One of these cells experiences large amounts of water and gravel overtop onto the promenade and its two main components are studied through three design parameters: gravel nourishment width, gravel nourishment height, and width of the submerged breakwater crest. Fifteen configurations based on the design parameters were experimentally tested under the same wave motion and sea level. Three main outputs were analyzed: gravel overtopping, water overtopping, and final equilibrium profile which included the height and distance from the promenade of the crest formed due to wave action. The results also showed that an optimization between the increase in gravel nourishment width and breakwater width must be found as a large increase in one minimizes the effectiveness of the other. Additional observations on the amount of gravel added and the classification of gravel beaches are also made.

Keywords: Submerged Breakwater, Gravel Beaches, Marina di Pisa, Experimental Modelling

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Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Amanda Zannella, Andrea Esposito, Irene Simonetti, Lorenzo Cappietti, *Adaptation of the coastal protection system at Marina di Pisa, to extreme sea conditions: experimental analysis of the submerged breakwater and gravel beach*, pp. 1030-1038, DOI: 10.36253/979-12-215-0556-6.90

Introduction

Marina di Pisa is a coastal town located on the Northern Tuscan coast on the Tyrrhenian Sea, at the south end of the mouth of the Arno River. The city has suffered from a long history of coastal erosion and coastal protection strategies which have contributed to its present state. The current coastal defense system at Marina di Pisa is composed of a large seawall along the coastal road, standing about 4 m above m.s.l. and extending south of the mouth of the Arno River for about 2.3 km. Additionally, about 50÷100 m offshore from the seawall, there are 10 rubble mount breakwaters ranging from 200÷270 m long and separated by a 15 m gap. Six of the breakwaters are emerged 1.0÷3.0 m above m.s.l. and the other four (in cells 7, 6, 5, 4, i.e. counting southward from the mouth of Arno River) are submerged about 0÷1 m below m.s.l. with gravel nourishment seaward of the existing seawall. Between the breakwaters, there are parallel rubble mount groins extending from the coast.

The present-day, heavily protected coast at Marina di Pisa is the result of decades of work and the implementation of various attempts at protection strategies, first through "hard" protection and slowly transitioned into a composition with "soft strategies". The first signs of erosion were evident right after the establishment of Marina di Pisa in 1872, when a large buffer of sandy beach still existed between the town and the sea. The first recording of a protective perishable structure against seen erosion is from a postcard of Marina di Pisa from 1915, which kickstarted a battle between the force of the sea and the attempt at land preservation with "hard" protective structures [12].

By the end of the 1960s the coast located south of the Arno's mouth was protected by groins, 2.3 km of seawalls (built in 1928), and 10 detached rubble mound breakwaters (built in the period 1935-1940 and 1965-1975), each 200÷270 m long, 3 m high above m.s.l., separated by 15 m wide gaps and about 50÷100 m off the shoreline [6] which can be seen in Figure 1a. The high investment in the protection of the coast has shown to be essential for the survival of Marina di Pisa. In Figure 1b, the erosion map recreated by Bini et al. [3] and the satellite image of Marina di Pisa in 1988 (Figure 1a) shows the difference in the evolution of the north and south of the mouth of the Arno River. A clear contrast in the erosion of the two sides of the river is evident as the south boundary was heavily guarded and the north side was left free to erode, losing more than 1 km of land.

Although Marina di Pisa has been protected by heavy interventions, erosion on the seabed south of the Arno River has not been controlled. Right after the construction of the emerged breakwaters, water depths immediately onshore of the breakwaters averaged approximately 2 m, whereas depths at the offshore foot of the breakwaters averaged 3 m. Because nearshore erosion has continued as a result of the decreased alongshore sand supply to the system, the offshore depths increased and are now between 5÷7 m. The increased water depths offshore of the breakwaters have allowed higher incident wave motions and have caused the breakwaters to frequently fail, requiring substantial maintenance and a complete reconstruction of the barriers with heavier rocks for the main armor layer. In this circumstance, the action of incident wave motions with increased energy caused higher mass flux through and over the detached breakwaters thus increasing the water level between the breakwaters and the seawall during storms, i.e., also called wave piling-up [6]. Under these conditions the seawall was frequently overtopped leading to flooding of adjacent streets and buildings, often causing the closing of the coastal road. In 2002, as a means to reduce overtopping and flooding, an artificial gravel beach (grain size D50=6 mm) was emplaced seaward of the seawall of cell 7. A severe storm in October 2003 (H_s=6.6 m, H_{max}=11.5 m, T_p=10.5 s at the La Spezia gauge) washed a substantial amount of water and gravel over the seawall and onto the streets, highlighting the nature of the problem [6]. The wave transmission at cell 7's emerged breakwater and the related wave piling-up in the breakwater's rear side was still too high, while the volume of gravel nourishment was still too low to relocate the shoreline at a safer distance from the promenade, even considering that the relatively small gravel grain size allowed their abundant displacement shoreward under the up rushing of waves on the gravel nourishment [7]. If the volume of the gravel nourishment was sufficiently larger and/or the wave transmission at the detached breakwater was sufficiently lower the gravel overtopping on the promenade would not have occurred. The response to the 2003 storm damage was to renourish in 2006 with larger grains, about 4÷8 cm and larger volume in an attempt to reduce the transport of sediment onshore of the seawall. Moreover, the detached breakwater was converted into a submerged breakwater and its crest was widened to enhance the dissipation of wave energy thus limiting the energy of the waves impacting the gravel nourishment [5]. In the following years, cell 7 has not experienced any further gravel overtopping on the promenade proving the effectiveness of this system in protecting Marina di Pisa.

Gravel nourishment became such an integral part of the protective system because its behavior under significant wave action differs greatly from sand due to many relevant factors, e.g. to its high permeability and the higher inertia of each sediment grain. The uprush of wave breaking is higher than the settling velocity of the gravel [10] which carries a large capacity of sediment transport onshore. The high permeability of the beach then allows for water infiltration which decreases the sediment transport capacity of the backwash [1, 4, 11]. This system of onshore transportation of gravel creates the most significant feature of gravel beaches, their crest, which naturally forms in response to higher energy from the ocean, triggered by higher periods and higher waves, creating a physical protection barrier to the coast. The high permeability and hydraulic roughness of gravel nourishment allow for large energy dissipation of waves [2]. The ability of gravel beaches to naturally form a protective barrier against coastal flooding, unlike sand that easily erodes, is the main characteristic that allows gravel nourishment to be a valuable option as a coastal protection system.

Currently, four out of the ten cells (cell 4, 5, 6, 7) at Marina di Pisa, starting from cell 7 in 2006 to cell 4 in 2018, have adopted the mixed "hard" and "soft" protection system, each composed of a submerged detached breakwater, gravel nourishment, sea wall, and groins framing the cell to prevent longshore transport of gravel (Figure 1c). Three of the cells have proven to be successful, but the protection level at cell 4 has been shown to still be unacceptable due to the persistence of large amounts of gravel and water overtopping on the promenade during major storms. In principle, the unsatisfactory protection level at cell 4 can be linked to the following differences in the coastal protection system's design concerning cells 5, 6, and 7: i) the smaller distance of the submerged breakwater to the seawall, ii) the higher water depths on the breakwater's seaward and shoreward sides toes; iii) the lower seawall crest level; and iv) the lower gravel nourishment crest level. The focus of this paper is to analyze, through 2-D experimental methods, the impact that the two major components of the current coastal defense system, the submerged breakwater and gravel nourishment, have on the behavior of cell 4 during major storms.

a) *b)* c)

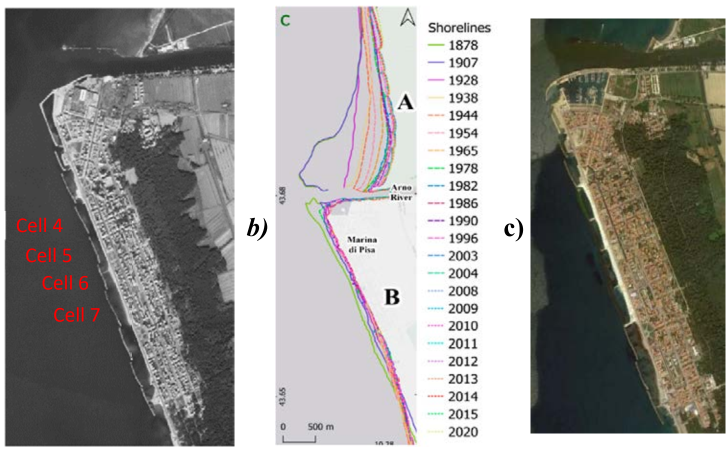

Figure 1– a) Marina di Pisa 1988 [8], b) Historical evolution of the coastline position at the Arno River mouth from 1878 to 2020 [3], c) Marina di Pisa 2021, with a naming convention for the cells (Google Earth).

Materials and Methods

The experiments were funded by the Region of Tuscany and were performed in one of the Wave-Current Flume (WCF) in the Laboratory of Maritime Engineering (LABIMA) at the Civil and Environmental Department of the University of Florence. The wave flume utilized is 37 m long, 0.80 m wide, and 0.80 m deep. It can produce a maximum wave height of 0.35 m within periods ranging from 0.4÷1.25 Hz [9], with a piston-type wavemaker. Due to the restrictions imposed by both the wave flume and the components of the model, the chosen scale for the model is 1:36. The section chosen for the 2-D experiment was retrieved by a bathymetric survey of cell 4, where the section, in relation to cell 7 had the following parameters: 1) smaller beach width; 2) deeper seabed on the submerged breakwater's shoreward side due to the presence of a hole; 3) deeper seabed at the submerged breakwater's seaward toe.

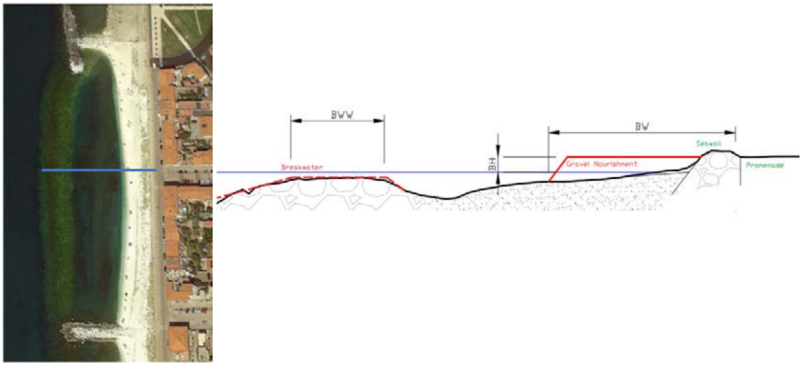

Figure 2 – Cell 4 2021 (Google Earth) (left), Configuration parameter (right).

The components of the model were designed based on Froude similarity. The current configuration at cell 4 on the chosen section, is composed of about 11.5 m of gravel nourishment from the promenade with a characteristic size of 4÷8 cm and it was represented by 1-2 mm gravel in the model with the extension of nourishment varying in height and width. The seawall stands at 4.5 m above m.s.l. with a crest of 4 m and stones of 1÷4 tons, it was represented as scaled-down dimensions in the model with 21÷84 g stones. The submerged breakwater has a crest of 20 m, -1 m below m.s.l. with stones of 5÷10 tons that were represented in the model with unchanging elevation but varying lengths of increasing crest width and with 105÷210 g stones in the model.

The test configurations were composed of the variation of the two main protective components of the cell: the submerged breakwater, and the gravel nourishment. For the fifteen tests carried, three main parameters varied: the extension of the current 20 m submerged breakwater (BWW = 30 m, 40 m, and 50 m seaside), the width of the gravel nourishment (BW = 40 m, 50 m, 60 m, 70 m) and the height of gravel nourishment (BH= 2 m and 3 m), Figure 2. The combination of varying parameters can be seen below in Table 1. The model was calibrated by reproducing the current state of the cell and testing it with a wave action that represented three recent storms, that caused gravel overtopping, with a maximum incident significant wave height of 4.1 m at the toe of the submerged breakwater, period of 12 s and sea level set up of 0.4 m.

Once the model was validated, all the other configurations were tested under the same extreme wave action that represented the worst-case wave motion that is physically possible in the 7 m water depths at the toe of the submerged breakwater. Therefore, the storm was represented by an incident significant wave height of 4.3 m at the toe of the submerged breakwater, a period of 12 s, and a set-up of 0.8 m with a duration of 6 h (significant height of 0.139 m, a period of 2 s, setup of 0.022 m and 1-hour test in the model). It is important to state that the tests were carried out with the initial profile of a flat and horizontal emerged berm of the gravel nourishment as it has been just nourished, which showed to be the worst-case scenario for overtopping for the specific nourishment lengths we tested as the gravel had not given time to form its crest, but the crest formation was forced to take place during the storm.

Results

The outputs of each test included an initial survey of the set configuration, a final survey conducted after the wave action, the amount of gravel overtopping in l/s/m, and the amount of water overtopping in l/s/m (Table 1).

Table 1– Parameters and outputs of test in Prototype

Test	Lab Code	Breakwater crest width [m]	Nour. Width [m]	Nour. Height [m] m.s.l.	Measured Gravel Overtop. (l/s/m)	Measured Water Overtop. (l/s/m)
1	C1	20	40	2	0.8	3.2
2	C2	20	40	3	0.3	1.4
3	C3	20	50	3	0.1	0.7
4	C4	20	60	3	0	0.1
5	C15	20	70	2	0.1	0.1
6	C7	30	40	2	0.1	1.4
7	C6	30	40	3	0	0.2
8	C8	30	50	2	0.2	0.8
9	C5	30	50	3	0	0.2
10	C9	30	60	2	0.1	0.1
11	C10	30	70	2	0	0.1
12	C11	40	60	2	0.1	0.2
13	C14	50	40	2	0.2	0.2
14	C12	50	60	2	0	0
15	C13	50	50	2	0.1	0.2

*The sea level considered during each test was +0.8 m above the m.s.l.

Discussion

Effects on Overtopping

The configurations accepted as effective are those in which the gravel overtopping was 0 l/s/m, and water overtopping was less than 0.1 l/s/m. Sensitivity analysis of both water and gravel overtopping against the increase of the width of the submerged breakwater as well as the increase in gravel nourishment was completed by keeping two out of the three parameters constant and analyzing the change in overtopping within the change of the third parameter. The analysis showed some expected results. With an increase in gravel nourishment width and height, there was a decrease in both water and gravel overtopping. Furthermore, an increase in the submerged breakwater width resulted in a decrease in water and gravel overtopping, although values of overtopping suggest that the effect of the increase of the extension of gravel nourishment is greater than that of the extension of the breakwater. Throughout the sensitivity analysis, it was also evident that while the submerged breakwater and gravel nourishment worked together to decrease the amount of gravel and water overtopping, an increase in one of the parameters eventually decreases the effectiveness of the increase of the other.

Figure 3 shows the decrease in effectiveness of an increase of breakwater width, as the gravel nourishment width (BW) increases.

Therefore, when working with this approach of coastal protection, it is imperative to have a combination where the effectiveness of both components is optimized. Interestingly, analyzing the nourishment with the same volume of gravel (Test 9 and Test 10) but different configurations of height and width showed that the initial profile does indeed have a direct impact on the amount of gravel overtopping, as the configuration with the greater height had less amount of gravel overtopping.

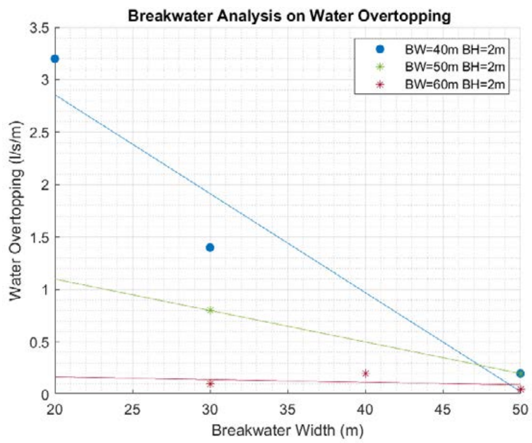

Figure 3 – Breakwater Analysis on Water Overtopping.

Effects on Final Profile

The amount of gravel nourishment and width of the submerged breakwater also had a direct impact on the position of the crest on the final profile, that in turn has great importance in controlling the occurrence of gravel overtopping on the promenade. If the gravel nourishment volume was not enough for creating a sufficiently large beach, then the morphodynamics would lead to the formation of the crest on the promenade which results in gravel overtopping. As seen in Figure 4, the parameter that most affected the position of the crest is the gravel nourishment width, as it increases the crest moves away from the promenade. The submerged breakwater has also been shown to have a similar effect but with a much lower effectiveness than the nourishment. Furthermore, the configurations that included a large amount of nourishment width and large breakwater form no crest, often starting with nourishment larger than 60 meters. This phenomenon can be due to large energy dissipation and the lack of space between the breakwater and nourishment that allows the waves to propagate in a way in which its interaction with the gravel nourishment is less effective in creating the crest.

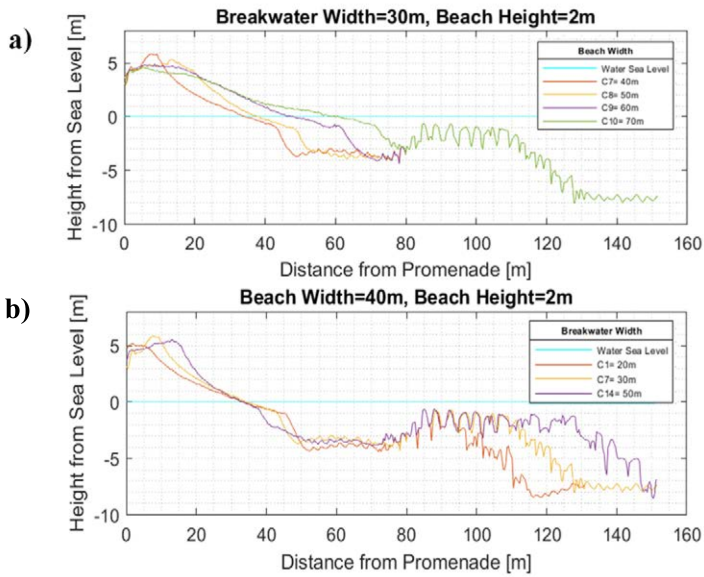

Figure 4 – Final Profile: a) beach width analysis; b) breakwater width analysis.

Conclusion

Marina di Pisa is a Tuscan coastal town (in Italy) that has endured years of coastal degradation with various attempts of diminishing erosion by coastal protection systems. The implementation of "hard" and "soft" protective structures has led to a large seawall against the coastal road standing about 4 m above m.s.l. and ten cells based on ten rubble-mound offshore breakwaters 50-80 m from the seawall. Six of the breakwaters are emerged standing 3 m above m.s.l., and the other 4 breakwaters (cells 7, 6, 5, 4) are submerged (-1 m below m.s.l.) and with gravel nourishment offshore of the seawall. Cell 4 at Marina di Pisa has not reached a satisfactory design as large amounts of water and gravel overtop onto the promenade during large storms. A laboratory experiment on a wave flume was designed and tested to examine three design parameters on the two main protective components, the submerged breakwaters and gravel nourishments of cell 4. The three design parameters tested were additional gravel nourishment width, gravel nourishment height, and addition to the submerged breakwater crest. Fifteen configurations based on different combinations of the design parameters were tested under the same wave storm action, and their effects were analyzed against three main outputs: gravel overtopping, water overtopping, and final equilibrium profile including height and position of the final crest formed by the gravel nourishment during the tests. The experiments have shown interesting results involving the combination of submerged breakwater and gravel nourishment. As expected, the enlargement of both the nourishment and breakwater results in less amount of gravel and water overtopping. Interestingly, the combination of a large enlargement in one of the components has shown to lower the need to also adopt the other component, therefore it is important to reach an optimal design where the effectiveness of all the components is equalized under the premise of economic affordability. The initial profile of the nourishment encompassing the initial gravel volume also has shown to have major effects on its final profile, especially the beach nourishment width that was correlated with the shift of the final crest away from the promenade. A combination of a large extension of the breakwater and beach nourishment also showed to have final profiles without a crest but a steady slope, as the short length between the breakwater and the nourishment did not allow for further wave propagation. The final crest position both in height and location has been shown to have an impact on the amount of overtopping. Lastly, the volume of gravel added as nourishment to the beach had a direct impact on the profile evolution and behavior as it mixed with sand, with the smallest amount of gravel creating mixed sand and gravel beach and changing the desired behavior of the gravel. It is important to notice that although the engineering component is key to a functional design, a successful design also includes social, economic, and environmental factors that are not discussed in this paper.

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FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Laura Bonora, Marcantonio Catelani, Matteo De Vincenzi, Giorgio Matteucci (edited by), *Tenth International Symposium "Monitoring of Mediterranean Coastal Areas: Problems and Measurement Techniques". Livorno (Italy) 11th-13th June 2024*, © 2024 Author(s), CC BY-NC-SA 4.0, published by Firenze University Press, ISBN 979-12-215-0556-6, DOI 10.36253/979-12-215-0556-6

MONITORING OF MEDITERRANEAN COASTAL AREAS: PROBLEMS AND MEASUREMENT TECHNIQUES

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2. Laura Bonora, Marcantonio Catelani, Matteo De Vincenzi, Giorgio Matteucci (edited by), *Tenth International Symposium "Monitoring of Mediterranean Coastal Areas: Problems and Measurement Techniques". Livorno (Italy) 11th-13th June 2024*, 2024

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Monitoring of Mediterranean Coastal Areas:

problems and measurement techniques

The 10th International Symposium *Monitoring of Mediterranean Coastal Areas: problems and measurements techniques* was organized by CNR-IBE in collaboration with Italian Society of Silviculture and Forest Ecology , and Natural History Museum of the Mediterranean and under the patronage of *University of Florence, University of Catania, Accademia dei Lincei, Accademia dei Geogofili, Italian Association of Physical Geography and Geomorphology, Tuscany Region, The North Tyrrhenian Sea Ports System Authority, Livorno Municipality* and *Livorno Province*. This edition confirmed the Symposium as the international occasion to present the research carried out in recent years on the monitoring of the Mediterranean Coastal Areas and therefore as a space to present new proposals and promote actions for the protection of the marine and coastal environment. In the Symposium, Scholars had illustrated their activities and exchanged innovative proposals, with common aims to promote actions to preserve coastal marine environment. In this 10th edition, in fact, we had more than 130 participants from 16 countries; this is a sign of great success and willingness to be presence in Livorno to discuss problems and propose solutions for the Mediterranean coastal areas.

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ISSN 2975-0288 (online)
ISBN 979-12-215-0556-6 (PDF)
ISBN 979-12-215-0557-3 (XML)
DOI 10.36253/979-12-215-0556-6
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