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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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).

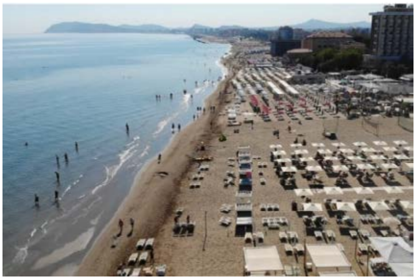
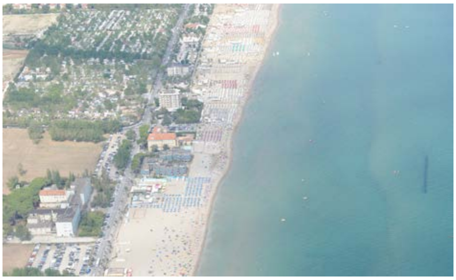
The end of the 1970s saw a worsening of the problem, with consequent political intervention: with the Regional Law n.7/1979, Emilia Romagna Region promoted the realization of a project plan for the defense of the coast.

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.

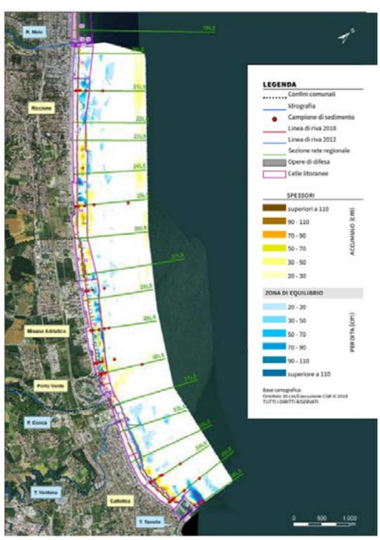
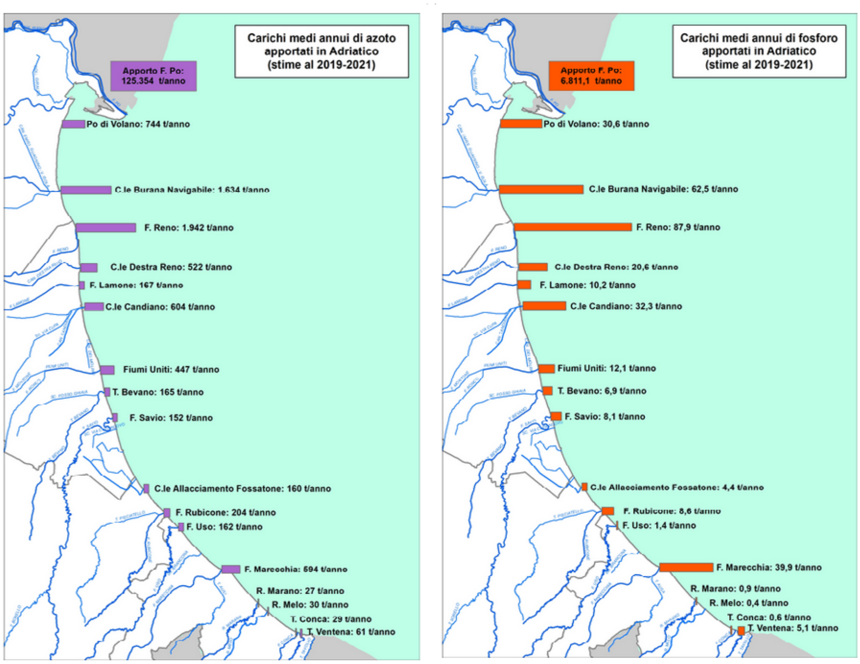


Figure 2 – Cattolica - Riccione’s harbour: Accumulation and Sediment Loss Chart 2012-2018 (SLEM-Arpae-2020).

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.

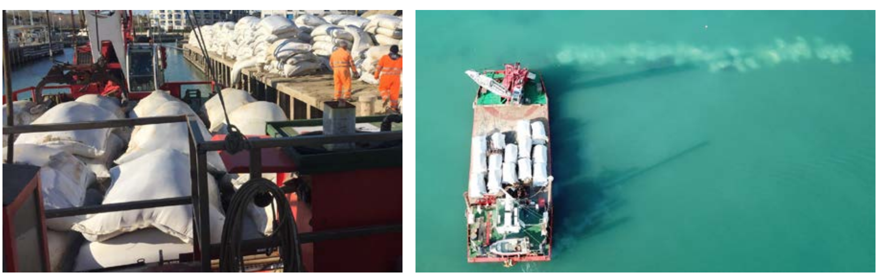
About artificial barriers, on the coast of Riccione it was chosen to experiment with systems of "underwater" reefs, contrary to what has been experienced in neighbouring territories, characterized by "emerged" barriers.

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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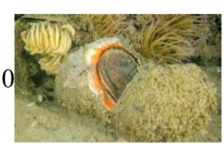
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Figures 9, 10 – Phylum Cnidaria – Class Anthozoa.
Figure 11, 12 – Phylum Mollusca – Class Gastropoda.


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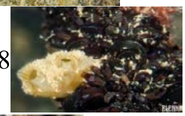
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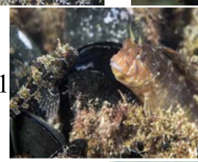
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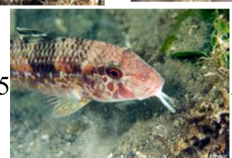
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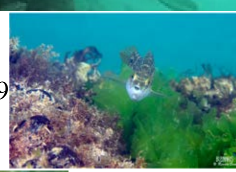
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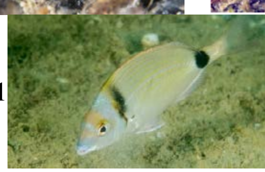
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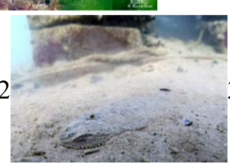
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Figures 13,14,15 – Phylum Arthropoda – Class Crustacea.
Figures 16,17 – Phylum Arthropoda – Class Crustacea.
Figures 18,19 – Phylum Chordata – Class Ascidiacea.
Figures 20 – Phyla Cnidaria – Class Scyphozoa and Arthropoda – Class Crustacea.
Figures 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

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