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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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.

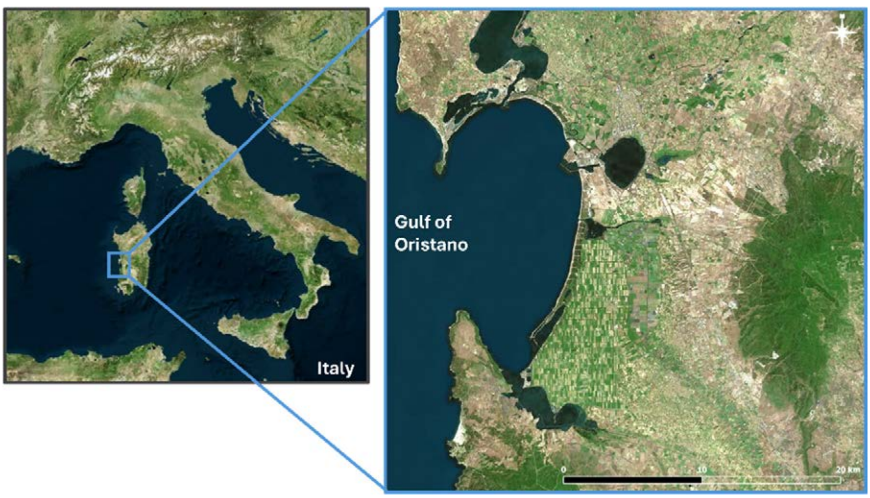

Figure 1 – Map of the location of the Gulf of Oristano (source: *Bing satellite*).

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.

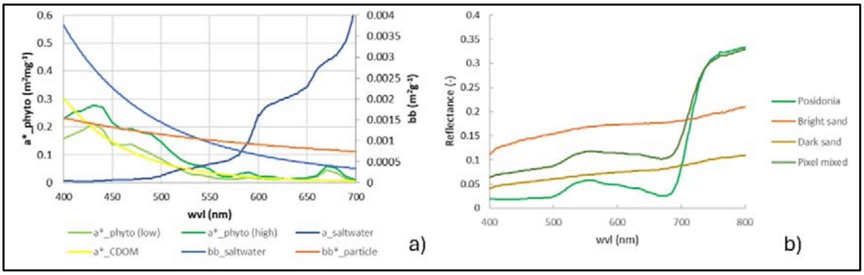

Figure 2 – (a) SIOPs of Oristano water used in the bio-optical model BOMBER code. *a_saltwater* is the absorption coefficient of pure sea water, *a*_phyto* is the chlorophyll-specific absorption coefficient of phytoplankton in two different conditions (low and high presence of phytoplankton measured 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.

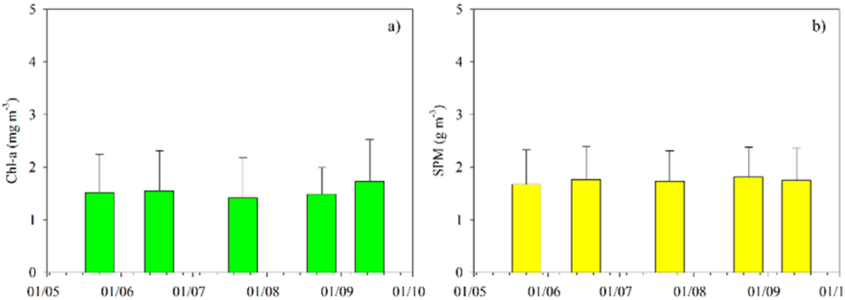

Figure 3 – Mean and standard deviation of chlorophyll-a (Chl-a) (a) and suspended particulate matter (SPM) (b) in the northern part of the Gulf of Oristano from Sentinel-2 images for the period from May to October 2022.

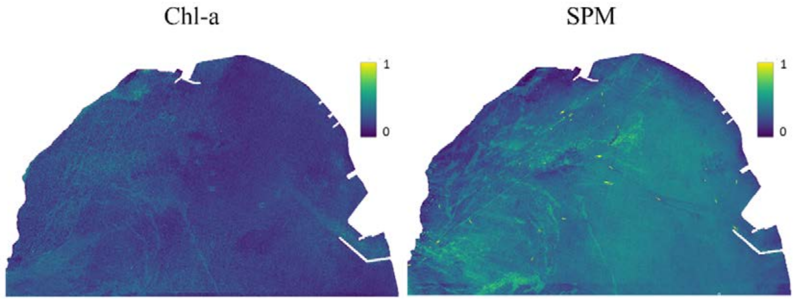

Figure 4 – Maps of the coefficient of variation of Chl-a and SPM concentration derived from Sentinel-2 data for the period May-October 2022.

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.

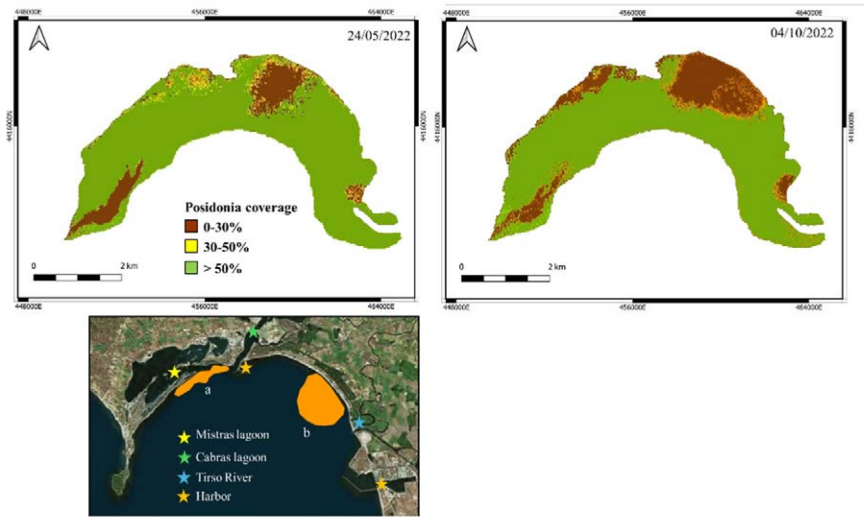

Figure 5 – Maps of the substrate coverage (percentage of *P. oceanica*) on 24th May (upper left) and 4th October 2022 (upper right) for the northern portions of the Gulf of Oristano from PRISMA images. In orange areas of higher variation in the percentage of coverage of Posidonia between the two dates.

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.

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