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# Marine benthic forms of the Marine Protected Area Capo Caccia-Isola Piana (Sardinia, Italy)

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**ABSTRACT**
The great ecological and economic value of the biocenoses of Marine Protected Area 'Capo Caccia-Isola Piana' (MPA) requires a constant monitoring. For this reason, a continuous study of the area producing overlapping maps useful to control in real time the evolution of the biocenoses is necessary. The integrated use of several methodologies, such as Side Scan Sonar, Remote Operating Vehicle and Drone, has allowed us to realize a very detailed map. This paper presents the marine benthic map of the MPA and compares the present situation with that recorded in 2008.

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*Posidonia oceanica*; biocenosis; human impact; Alghero; Mediterranean Sea

## 1. Introduction

One of the main topics related to the conservation of marine environments is the *Posidonia oceanica* seagrass meadow in its worldwide regression. For its importance, the topic has been included in the EC Directive 92/43/EEC (http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm). The meadow plays an important role in protecting (i.e. reducing the wave energy) and nourishing (i.e. supplying bioclastic material) the beach systems (De Muro, Batzella, Kalb, & Pusceddu, 2008; Manca, Pascucci, De Luca, Cossu, & Andreucci, 2013; Pergent, Pergent-Martini, & Boudouresque, 1995; Vacchi et al., 2017). Therefore, a detailed and continuous mapping of the seagrass distribution may ensure its conservation (De Muro & De Falco, 2015; Tecchiato, Collins, Parnum, & Stevens, 2015). However, issues such as the distribution of other benthic communities, environmental modifications and human impact have to be considered as well to evaluate the ecological status of coastal areas to plane future strategies (Buosi et al., 2017; De Muro, Ibba, & Kalb, 2016; James, 2000).

Marine protected areas (MPAs) have been established to keep in their natural state areas to conserve biodiversity and protect species. They are created by delineating zones with permitted and non-permitted uses (Kelleher & Recchia, 1998). Under this purpose, on 2002 the MPA of 'Capo Caccia-Isola Piana' (NW Sardinia, Italy, Central Mediterranean Sea) was established by the Italian Ministry of Environment (Figure 1). One of the aims of MPA has been since the beginning the knowledge of the ecological communities present in the area and to estimate the economic value of the biocenoses. In this context, this paper presents the distribution and status of the benthic communities of the MPA imaged in a 1:12,000 scale map. Particular attention has been given to the mapping of the wide *P. oceanica* meadow. The seagrass mostly lies within the bay of Porto Conte (Figure 1 and main map). This particularly sheltered bay is intensely frequented, especially during the summer season, from nautical pleasure, exposing it to an intensive anthropic impact. Impact also enhanced by the presence of two tourist ports (Tramariglio and Porto Conte) (Figure 1). The bay is also a preferred site for fishing both traditional and trawling. It has been documented that this last type of fishing irreversibly changes the matte, causing deep grooves that contribute to accelerate the degradation of the *P. oceanica* meadow itself (Milazzo, Badalamenti, Riggio, & Chemello, 2002). Degradation is evidenced by large extensions on the sea surface of dead matte and by the presence of low-density plants as well as by the regression of its upper limit (Chessa et al., 1988; Cossu, Gazale, Orrù, & Pintus, 2001). The current distribution of the biocenoses presented in the map has been compared with that mapped on 2008 (Figure 2) to underline changes occurred in the MPA in a decade.

## 2. Study area

The MPA of 'Capo Caccia-Isola Piana' (40°34′N–8°13′E) extends from Punta delle Gessiere to Capo Galera, it has 36,144 km of coastline and a sea extension of 2631 ha (Figure 1).

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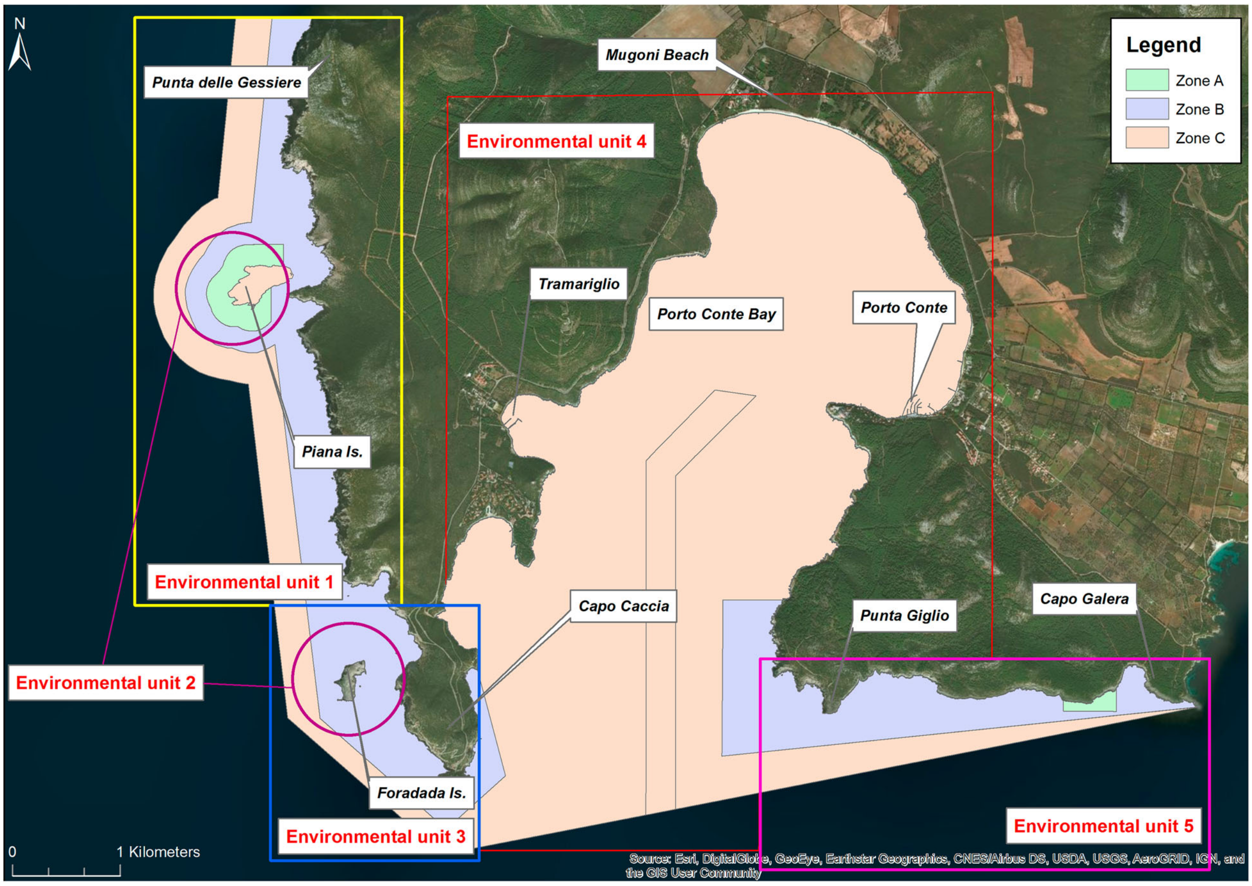


**Figure 1.** Study area. Red lines delimit Zones A (total restriction), B and C of the Marine Protected Area. Squares indicate the five defined environmental units of the Biocenotic Map. Image is from ESRI, Open street map. Environmental units.

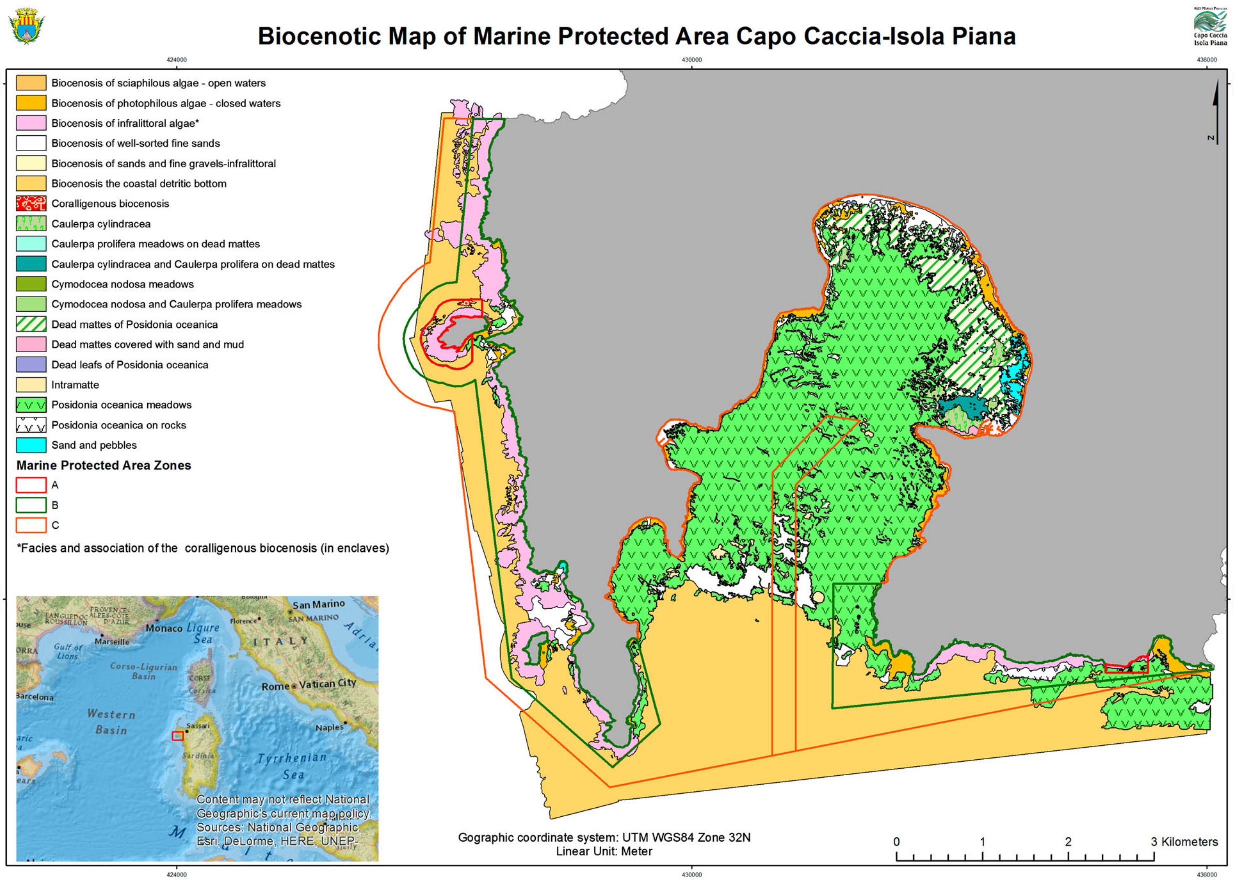


**Figure 2.** Biocenotic realized in the 2008 by the Marine Protected Area 'Capo Caccia-Isola Piana'. The map is available at http://www.ampcapocaccia.it/ricerche.asp.

The present morphological setting of the MPA formed since about 3 ka BP when the post Last Glacial Maximum (20 ka BP) sea level rise decreased (Magny & Combourieu Nebout, 2013; Pascucci et al., 2018; Pascucci, Sechi, & Andreucci, 2014 and ref therein). Similarly, the present climate started to establish between 6 and 5 ka BP and become stable about 3 ka BP, after which small amplitude climate fluctuations (0.5–1°C) occurred (Pascucci et al., 2018).

The coast bordering the MPA is characterized by high rocky cliffs, often articulated in promontories mostly delimiting small bays where sand and/or gravelly pocket beaches occur. In places, rocky cliffs are incised by wave action, developing tidal notches (Antonioli et al., 2015). On the NE landward side of the Porto Conte Bay, there is the biggest and most important beach of the MPA, the Mugoni Beach (Figure 1). Beaches are nourished by clastic sediments fallen and/or eroded from the cliffs or carried by a complex system of ephemeral streams active during winter major rainfalls. Most of the bioclastic sediments derive from shell organisms living in the extensive *P. oceanica* meadow occurring all along the MPA at depth comprises between −4 and −30 m and transported to the beaches during major storms (De Falco, De Muro, Batzella, & Cucco, 2011; Manca et al., 2013). The dominant effective wind is from the northwest (Mistral wind) and is responsible for the longshore drift (Donda et al., 2008; Manca et al., 2013; Vicinanza, Contestabile, & Ferrante, 2013); the sea is microtidal with storm waves up to about 7 m high. The average sea temperature measured during 2017 was about 16.5°C (https://www.seatemperature.org).

### 2.1. Geological setting

Sardinia is the second biggest Island of the Mediterranean Sea and represents a segment of the south-European plate that was separated from the European continent during the early Miocene (Cherchi & Montadert, 1982; Doglioni, Gueguen, Harabaglia, & Mongelli, 1999). The studied area can be sketched as a bay (the Porto Conte Bay) delimited by two headlands (Capo Caccia and Punta Giglio promontories) (Figure 1). The promontories are composed of Triassic to Cretaceous carbonates deposited when Sardinia was part of the northern side of the Neo-Tethys (southern margin of the European plate) (Simone & Cherchi, 2009). In particular, they are made of limestones composed of Triassic-early Jurassic paralic and coastal deposits, early Cretaceous shallow water platform deposits and late Cretaceous Rudist-rich limestones. Late Quaternary marine to alluvial deposits crop out along the low relief part of the Porto Conte Bay and formed as a consequence of the last 300 ka sea level fluctuations (Pascucci et al., 2014). Marine deposits mainly consist of conglomerates, shallow-marine fossiliferous carbonates, and sandstones referred to the interglacial stages. Non-marine deposits consist of coastal aeolian sandstones interlayered by fine-grained sandstones and siltstones (colluvia and paleosols) and alluvial conglomerates, which are usually attributed to glacial stages (Andreucci, Clemmensen, Murray, & Pascucci, 2010; Pascucci et al., 2014). The 1.6 km long and just 30 m wide Mugoni beach-lagoon system is formed during the latest stages of the Holocene sea level rise (Palombo et al., 2017). The beach is mostly composed of medium to coarse sand, whereas fine sand and silty deposits thinly cover the back shore marsh plain (Ratto, Montis, Depalmas, Rendeli, & Melis, 2016). The marsh was reclaimed during the period 1936–1955 (Tedde & Farris, 2016).

## 3. Methods

The marine benthic map was made by the integrated use of Side Scan Sonar (SSS), submarine surveys and aerial photo and satellite images analyses. These integrated systems have allowed distinguishing the biocenoses present inside the MPA. The used SSS is a KLEIN 3000 with a dual frequency of 100 and 500 KHz (Klein Marine Systems, Salem, NH, USA). The survey was made with a slate range of 150 m and a line spacing of at least 20%. The SSS was towed with an 8.5 m long (Jenneau Merry Fischer) boat, equipped with a Trimble GEOXT Differential Geographic Position System (DGPS) and a Raymarine C80 GPS integrated with echo sounder. Submarine survey was performed with a Remote Operating Vehicle (ROV) 'Velociraptor' (Enne Elettronica, Savona, Italy). It was equipped with a high-quality video camera with grand angular lens providing a field view of 80° and with two 50-W halogen spotlights. The used aerial photos are Ortofoto 2008 (Regione Sardegna, RAS) and BaseMap Esri images (Digital Globe) with a resolution of 0.5 m and accuracy of 10.2. Additional aerial photos have been acquired with an Unmanned Aerial Vehicle (UAV) DJI Phantom 3 Advanced Drone equipped with a 12 mpixels camera mounted on three axis gimbal support to ensure the maximum stability.

The final map of biocenoses was edited at a scale of 1:12,000. The map was made interpreting a 0.250 m pixel resolution SSS mosaic integrated with aerial photo interpretation. Truthing points were acquired using the ROV images and direct scuba dives.

## 4. Results

The MPA has been ideally subdivided into five environmental units (Units 1–5), characterized by different ecological-environmental characteristics, representing areas with similar biocenotic and morphological conditions and analogous human activities (Figure 1). For the legend of the biocenosis, we referred to Pérès and Picard (1964). Data presented in the main map have been compared with those mapped in 2008 (http://www.ampcapocaccia.it/ricerche.asp) (Figure 2). The main differences are discussed in the text.

*Environmental Unit 1* 'The Western Cliffs' has an area of 530 ha (Figure 1). The main benthic communities are *Biocenosis of coarse sands and fine gravels under the influence of bottom currents-Brown algae*, representing more than 60% of the total, *P. oceanica meadows* 14% and *Biocenosis of the upper infralittoral rock* 17%. The main difference with the 2008 biocenotic map made is the extension of the *P. oceanica meadow*, which represented only 3% of the mapped area.

This environmental unit has a medium protection level (Zones B and C, Figure 1). In the area, only the underwater fishing is not allowed. All others activities such as navigation, professional fishing, sport fishing and anchoring are allowed under certain regulation. Anchoring occurs occasionally and only in some of the small embayments present along the cliffs. No mooring buoys are present; however, the considerable distance of this area from the ports made the human attendance very low.

*Environmental Unit 2* 'The small islands of the western cliff (Foradada and Piana)' has an area of 37.6 ha (Figure 1). The main benthic communities are *Biocenosis of the upper infralittoral rock with the presence of Cystoseira spp. and P. oceanica* (52%) and *P. oceanica on rocks* (21%), this latter was not mapped in the 2008 map (Figure 2).

The protection of this environmental unit is medium-high including areas with full (Zone A Piana Is) and general protections (Zone B Foradada Is) (Figure 1). In Zone A, the only activities permitted are scientific research and emergency assistance, whereas in Zone B, navigation, sport fishing and anchoring are allowed. No mooring buoys are present; however, the morphology of the Foradada Island strongly reduces the anchoring possibilities to small boats (mostly rubber dinghies).

*Environmental Unit 3* 'Capo Caccia Promontory' has an area of 139 ha (Figure 1). The promontory is interested by bottom currents coming from the north and bending to the east after the cape. The presence in the northern side of the promontory of numerous submerged karstic caves allows developing of sciafilous biocenoses. In the southern side, biocenoses are more susceptible to the light. Of particular interest are the mediolitoral communities with considerable presence of *Lithophyllum byssoides*, which is here very well developed and forms continuous ridges (*trottoirs* of Pérès & Picard, 1964) all along the cliffs where the tidal notch is better developed (Figure 3). The seafloor consists predominantly of medium sands bearing *Dyctiotales* and *Cystoseira* algae and is characterized by alternation of dense vegetation and wide bare sands. In the bay, close to the cliff, there is an impoverishment of the vegetation component with facies at *Oloturie*.

The main benthic communities of this unit are *Biocenosis of coarse sands and fine gravel under bottom currents* representing 67% of the surface, *Biocenosis of the upper infralittoral rock in sheltered waters* 17% and the *P. oceanica meadows* 14%. The main difference with the 2008 map is the extension of the *P. oceanica meadow*, which occupied 6% of the unit area (Figure 2). It should be noted that in the previous map was indicated the presence of the *Biocenosis of fine sands in shallow waters* which, in our opinion, is not present both for the strong bottom currents and for the presence of diffuse megaripples in the unit area (main map).

This environmental unit has a medium protection level (Zones B and C, Figure 2). Most of the human presence is related to motorboats for collective transport (guided tours and scuba divers) and sport fishing. This last is just allowed with rod and line only. Anchoring occurs just occasionally at the foot of some cliffs where the water depth does not exceed 10 m. Mooring buoys are present in some of the most attended scuba diving sites.

*Environmental Unit 4* 'The Porto Conte Bay' has an area of 1754 ha; that is, the largest unit of the MPA (Figure 1). The main benthic community is represented by the *P. oceanica meadows,* which occupies 958 ha, accounting for 55% of the total area (main map). Intramatte channels are very numerous (over 360 have been mapped) and occupy about 40 ha. Channels size ranges between 1000 and 3000 $m^2$, which clearly indicates a non-natural origin of them. It should be noted that the larger channels are located in the most distal part of the meadow at depths between −18 and −30 m. In the bay, the *Biocenosis of coarse sands and fine gravels under the influence of bottom currents-Facies at Spatangoid* is also well represented. It occupies the 21% of the total area and is confined below the lower limit of *P. oceanica* meadow (below −30 m). The present survey shows substantial differences with the 2008 map in the number and size of intramatte channels (Figure 2 and main map).

This environmental unit has a low protection level (Zone C, Figure 2). This area, because sheltered, is highly used by tourism boats and as anchorage of ships during storms. We claim that most of the recognized intramatte channels could be related to anthropic phenomena. In particular, those occupying the central part of the Porto Conte Bay, at the depth around −20 m, to ship anchorages, whereas those occurring at shallow depth to both anchoring and trawling. This last type of fishing is made illegally in the bay. Moring buoys, although present, are not sufficient for anchoring the large number of boats sailing the bay during the summer season.

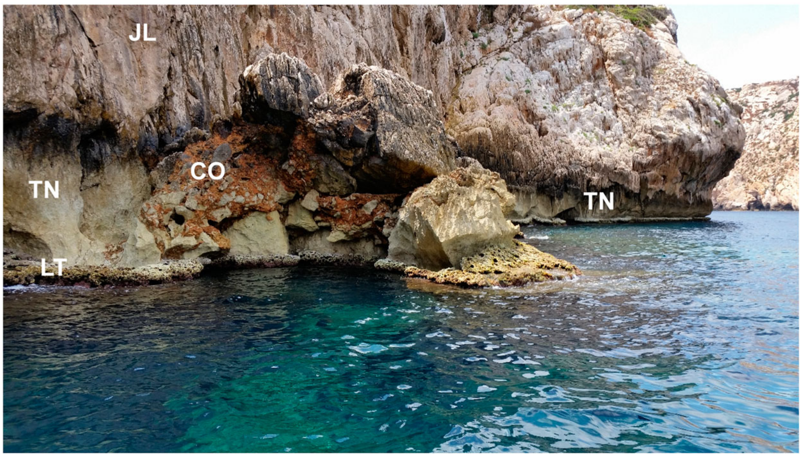


**Figure 3.** Mediolitoral communities: *Lithophyllum byssoides* developed on the tidal notch where it forms continuous ridge (trottoir). JL: Jurassic Limestones; CO: Quaternary Colluvium; TN: Tidal notch; LT: *Lithophyllum byssoides*.

*Environmental Unit 5* 'The promontory of Punta Giglio' has a surface of 247 ha (Figure 1). The main benthic communities are represented by *Biocenosis of coarse sands and fine gravels under the influence of bottom currents-Megaripples* representing 61% and *P. oceanica meadows* occupying 26% of the area. In addition, the *Biocenosis of the upper infralittoral rock* and *Biocenosis of the upper infralittoral rock in sheltered waters* are well represented. The main difference with the 2008 map is the extension of the *P.oceanica* meadow (Figure 2). *The Biocenosis of fine sands in shallow waters* and *Biocenosis of well-sorted fine sands* mapped in 2008 in our opinion are not present, given the presence of strong bottom currents megaripples in the unit area. Our interpretation indicates only the presence of *Biocenosis of coarse sands and fine gravels under the influence of bottom currents-Facies a Spatangoid.*

This environmental unit has a medium-high protection level including areas with full and general protections (Zones A, B and C, Figure 1). Most of the human presence is related to navigation. Anchoring is allowed only in definite areas mostly served by mooring buoys.

## 5. Conclusions

Mapping plays a key role in the management and conservation of natural systems. In MPAs, where sustainable development is always subordinate to conservation efforts, maps are mostly used to represent habitats, development pressures, tourist facilities or legal restrictions such as the zoning of a protected area (De Muro et al., 2018; Rovere et al., 2013). The newly produced biocenotic map of the Marine Protected Area 'Capo Caccia-Isola Piana' may therefore represents a fundamental tool for the future monitoring of the conservation status of the benthic communities. The map has underlined that the most important biocenosis of the area is the *P. oceanica meadow*. It has also highlighted that although the MPA is covered by limitations, only Zones A and B are effectively protected. The wide area of Porto Conte Bay is the most human attended because sheltered and easy to reach. The city of Alghero is just 7 miles far and the other two touristic ports present in the bay make easy to navigate in it. Pleasure, sport fishing, fishermen and touristic boats sail and anchor in the bay without any significant control. The several intramatte channels mapped and not recognized in the work of 2008 claim for an important deterioration of the meadow with consequent regression of its upper limit. This deterioration is most probably linked to anchoring and illegal trawl fishing conducted in the area. This intense human activity in the bay may have yield an increase in the turbidity of the marine superficial water with the consequent fragmentation and retreat of the *P. oceanica* meadow upper limit. This effect is similar to the more large-scale environmental deterioration phenomenon that is affecting many highly anthropized sections of the Sardinian coast (De Muro et al., 2018). The work, finally, clearly states that areas with integral protection (mainly environmental Unit 2 and in part Unit 3) are functional to the protection of benthic communities. The comparison with the map of 2008 has indicated an increase of 20% of the *P. oceanica* meadow in the areas. We therefore hope in a continuous monitoring of the protected areas producing overlapping maps useful to control in real time the evolution of the biocenoses.

## Software

SonarPro® Package (Klein Marine Systems, Inc.) is the software used for Side Scan Sonar data acquisition, whereas the data processing was performed with Sonarweb (Chesapeake Technology). Spatial analyses were performed and processed using ArcGIS Desktop version 10.5.1 (ESRI).

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