New technologies for the detection of natural and anthropic features in coastal areas

Some results of the sub project GE.RI.N (Natural Resources Management) conducted in the Marine Protected Area of Egadi Islands (Western Sicily) are presented. Coastal and seafloor morphology has been investigated integrating different data sources and using remote sensing data acquired by the Ministry of Environment during the MAMPIRA Project. This approach allowed us to recognize the real extent and distribution of several rocky outcrops emerging from the sandy bottom, south of Favignana Island (known as "I Pali"), and the anthropogenic features generated by the effects of traps, trawling and anchor on the *Posidonia oceanica* meadow that, within the Egadi Archipelago, is the largest in the Mediterranean Sea [1] (www.ampisoleegadi.it). Unpublished and detailed characterization of the seafloor and assessment of human impacts are the main results of the present study, which demonstrate how remote sensing technologies have a great potential and relevant management implication for Marine Protected Areas and the preservation of emerged and submerged environment

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Introduction

The management of natural resources is particularly important in coastal environments, especially in Marine Protected Areas (MPA), where human activities and conservation of natural habitats have to be balanced according to a sustainable development.
To achieve this objective, direct and indirect environmental investigations were carried out in order to characterize and monitoring the emerged and submerged environment with innovative technologies. Among the many activities of the GE.RI.N project, the morphology of the coastal environment (both emerged and submerged) was investigated with GIS and remote sensing tools. The seafloor of the Egadi archipelago (~54,000 hectares) hosts several itineraries for Diving (http://favignana.santateresa.enea.it/) and it has been colonized by the most extensive *Posidonia oceanica* meadow of the Mediterranean Sea (~7,700 hectares) [2].
From the geological point of view, the island of Favignana has a N-S oriented synformal ridge (known as Montagna Grande), formed by a continuous succession of Mesozoic limestone and dolostone. Its slopes are quite steep and affected by landslides (especially in the eastern sector). Part of the ridge is lowered by extensional tectonic elements and covered by two more recent (Pliocene and Pleistocene) flat arenaceous deposits that, in the eastern part of the island, are improperly called "*tufi*" [3].
Many gravelly and sandy pocket beaches are spread along the coast belt, often bordered by steep calcareous/arenaceous cliffs [4]. Sedimentological characteristics and organogenic content of these deposits suggest an infra-littoral origin [5]. Some of these cliffs, (e.g. Cala Rossa, Bue Marino and Cala Azzurra) are affected by significant slope instability [6].

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From an oceanographic point of view, this area presents a complex water circulation because located between the western and eastern basin of the Mediterranean Sea. It undergoes, therefore, to water mass mixing effects. The range of transition produces significant changes in the thermohaline structure, with vortices and spots of biodiversity and high productivity. The Egadi archipelago is characterized by deep and surface currents, which can reach high speeds (especially inside the submarine canyon separating the island of Marettimo from Favignana and Levanzo), whereas deployments of current meter SD6000® conducted between September 2000 and January 2001 on the shoreface of Cala Azzurra at 9 to12 m depth, revealed clockwise currents with speed values ranging between 4,4 and 8,2 cm/s.

In stratigraphic and sedimentological terms, we are now living in the Holocene, the geological epoch that began 12,000 years ago after the Pleistocene. Nevertheless, P. Crutzen, Nobel Prize for Chemistry in 1995 for his studies on the ozone hole in Antarctica, coined the term Antropocene in order to define this last part of Holocene and identify it as the first geological era, in which human activities have been able to influence the natural balance of the Planet.

The Anthropocene [7], is a term widely used to denote the present time interval, in which many geologically significant conditions and processes are profoundly altered by human activities. These include changes in:

- erosion and sediment transport associated with a variety of anthropogenic processes, including colonisation, agriculture, urbanisation and global warming;
- the chemical composition of the atmosphere, oceans and soils, with significant anthropogenic perturbations of the cycles of elements such as carbon, nitrogen, phosphorus and various metals;
- environmental conditions generated by these perturbations; these include global warming, ocean acidification and spreading oceanic 'dead zones';
- the biosphere both on land and in the sea, as a result of habitat loss, predation, species invasions and the physical and chemical changes noted above.

In the present study, manmade features have been mapped in the emerged and submerged environment within the Egadi archipelago, which seems an "open laboratory" for Antropocene studies.

Data and materials

Several sources of information were consulted and raster and vector available dataset collected, organised, geo-referenced and re-interpreted. Layers inherent to cartography, topography, bathymetry, marine biotic communities, geology, hydrogeology, use of soil, vulnerability and the geological risk (landslides along stretches of coastline subject to coastal erosion in particular), were implemented. The data, provided by the Town Hall and the Egadi Islands' MPA, integrated within the Geological mapping, the PAI and the Regional Technical Cartography (Figure 1), were georeferenced and transformed into a single reference system (WGS84) to obtain a geographically coherent database.

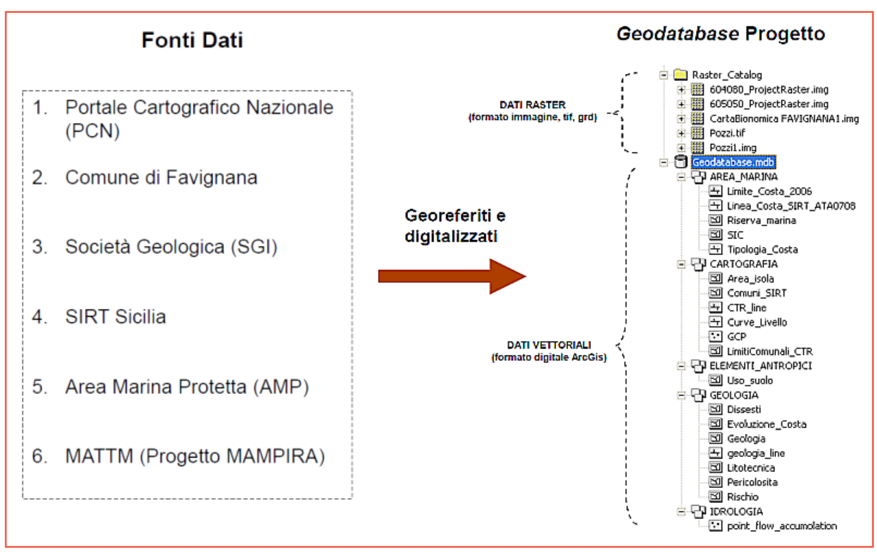

FIGURE 1 Structure of the Geodatabase

Research & development

To characterize and map the seafloor, an important contribution has been provided by remote sensing data collected by the Ministry of Environment during the MAMPIRA project (Monitoring of Marine Protected Areas Affected by Environmental Offences). A description of the dataset acquired through aerial surveys on May-August 2012 is reported below; technical specifications of the main sensors are reported in Table 1.

1. Topographic dataset of the coastal strip – products derived from high resolution topographic LiDAR survey (DSM first, last DSM, DTM, points xyz, intensity).
2. Bathymetric dataset of Marine Protected Area– merging of bathymetric LiDAR up to 40 m of depth and and Multibeam survey at greater depths.
3. Multispectral Dataset of Egadi Islands - 102 bands in the spectrum of visible, near infrared, and thermal acquired with MIVIS sensor (Multispectral Infrared and Visible Imaging Spectrometer) radiometrically, geometrically and atmospherically corrected [8; 9].

Method

All available information and environmental data were organized to make a geo-database easily upgradable and integrated over time. A Digital Elevation Model (DEM) using topo-bathymetric data was realised linking the two Multi-Beam (40-70 m of depths) and LIDAR (up to -40 m) datasets. The DEM was obtained by creating a mosaic of 65 plates (0.04°, each corresponding to a side of about 4 km), with a total area of about 665 km^2. Then, a shading and lighting relief were applied to better highlight the morphology of the DEM area. Finally, for spots of particular interest, specific maps of slope and exposure were created for the interpretation of seafloor morphology and sedimentary structures.

The remote sensing data were also integrated into the GE.RI.N geo-database to be processed and compared with other information layers, in order to support the interpretation of the geological and geomorphologic elements derived from the DEM. During the MIVIS survey, a spectral radiometric *in situ* survey was made at ground for calibration and validation of the data collected by plane. The *in situ* spectral measurements were carried out (in collaboration with ENEA) in several stations on sandy and mixed (rocky and sandy) seafloor, at a depth of over 20m [8]. At that point, the *P. oceanica* meadow was still visible from the boat. In each station, samples of surface sediment were collected with a Van Veen grab. Grain size distribution was then determined by gravimetric dry sieving methods. A watchdog control unit was installed at about 10 m of height to monitor the intensity and direction of wind, precipitation, temperature between July 2012 and July 2013.

Results and discussion

Geomorphological and sedimentological structures on seafloor were examined through the analysis of

Parameter	Dataset Topography	Dataset bathymetry	Dataset multispectral
Sensor Used	ALTM Gemini – ALTM Pegasus	scan FugroMK3/MULTIBEAM SeaBat 8160	MIVIS
Resolution Medium	0,8 pt/m^2	0,25 pt/m^2	3X3m
Scanning Frequency	100-70 kHz	1,5 kHz	
Side Lap	30 %	30 %	
Planning Resolution	~2 m	~4 m	
Planimetric Altimetry	± 0,30 m	± 0,50 m	
Altimetric Accuracy	± 0,15 m	± 0,50 m	
Spectral Bands	-	-	102
Visible (20 bands)	-	-	0,43 – 0,83 µm
Near Infrared (8 bands)	-	-	1,15 – 1,55 µm
Middle Infrared (64 bands)	-	-	2,0 – 2,5 µm
Thermal infrared (10 bands)	-	-	8,2 – 12,7 µm

TABLE 1 Technical characteristics of remote sensing data

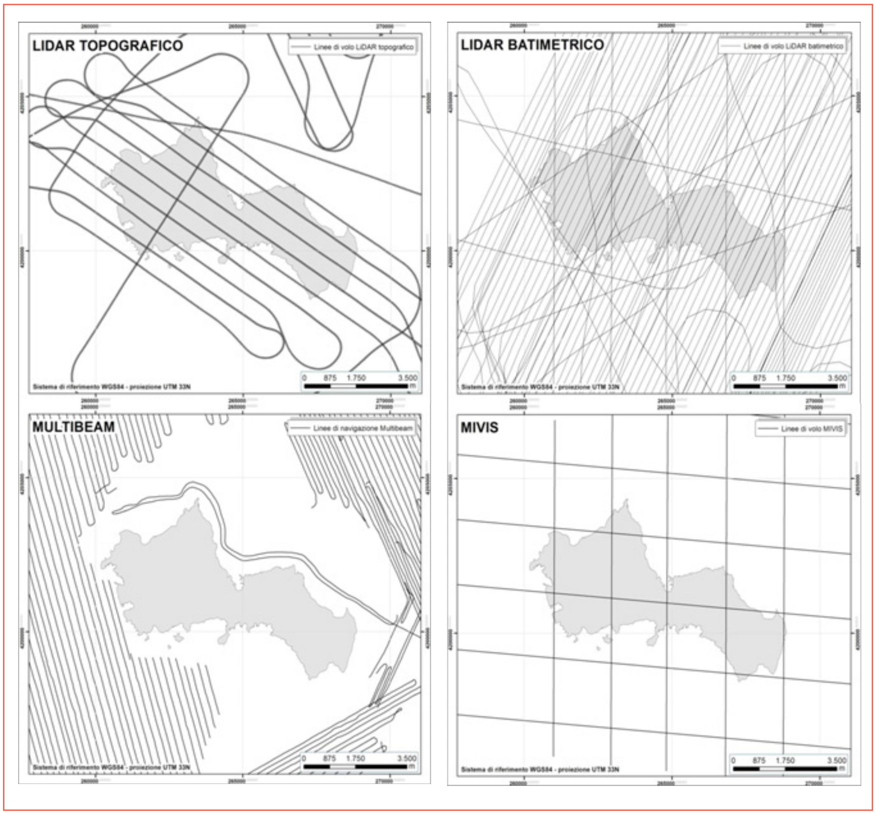

FIGURE 2 Trajectories acquisition of topographic, bathymetric and multispectral data

the existing maps, the Digital Elevation Model and hyperspectral data acquired under the project MAMPIRA, the accuracy of which has been improved thanks to direct and indirect in-situ investigations. The seafloor morphology is highly different with rocky and sandy shoreface, submarine canyons, vermetidi's *trottoir* and shoals of high rocky outcrops. A number of morphological elements influenced by tectonics, by changes in sea level and erosion due hydrodynamics can be observed. There are also many submerged forms ever detected so far. Some of them are described as follows.

Shoals

The study area is characterized by a variety of seafloor geological and geomorphological features. South of Favignana Island, at a depth of 19 to 50m, many rocky shoals sharply rising from the bottom were found (Figure 3).

FIGURE 3 Results of the topo-bathymetric surveys of Favignana Island. The angle of shading is 315°. Up left a rose diagram of wind speed and direction

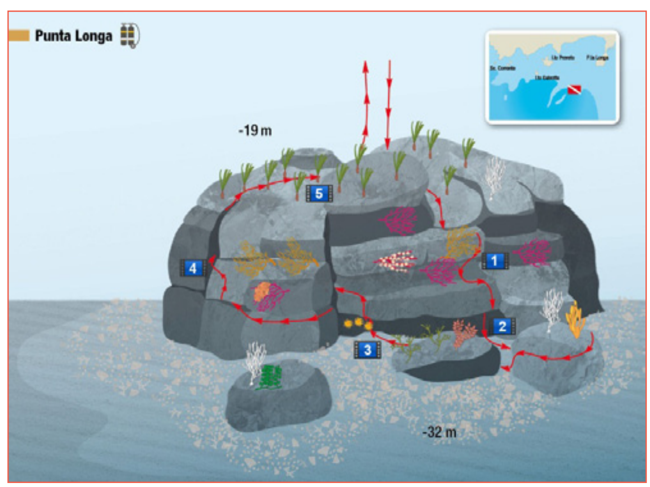

FIGURE 4 Draw of Punta Longa Palo, signalled by [5].
Source: http://favignana.santateresa.enea.it

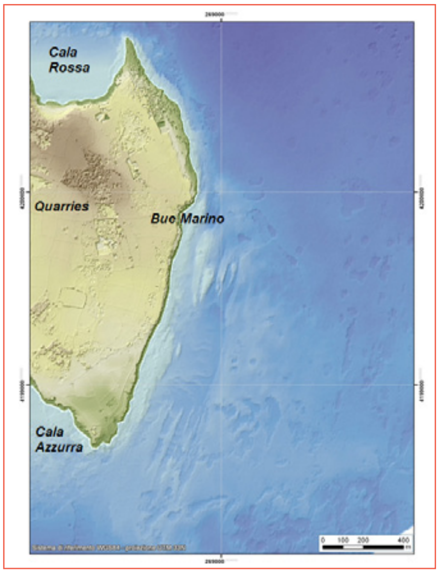

FIGURE 5 Depressions on sandy bottom along the east coast of the island of Favignana

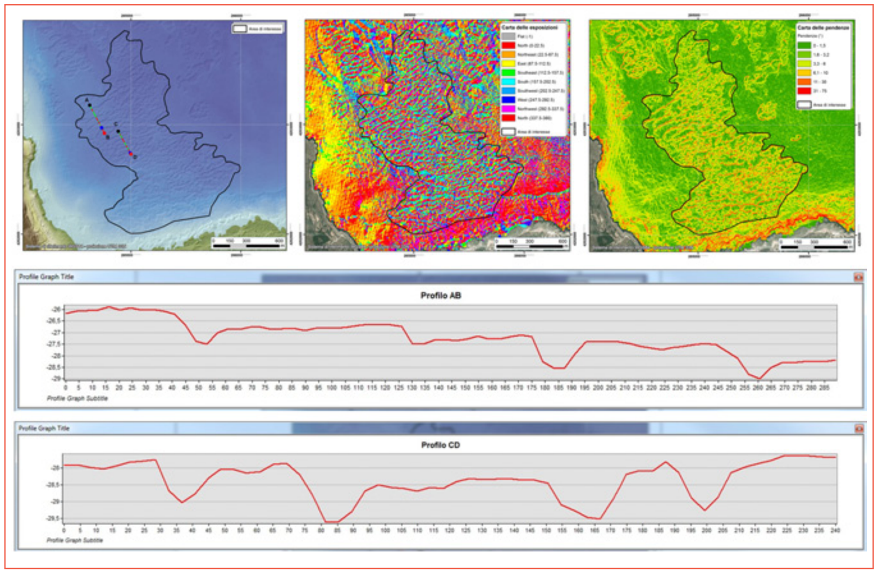

FIGURE 6 At the top bathymetric, slope and lighting maps are reported. Below, anthropogenic furrows and asymmetry of superimposed sedimentary structures are observed along two NW-SE oriented transects

These morphostructures, also known as "Pali", are shoals with subvertical walls partially reshaped by the erosive action exerted during the last Holocenic sea level rise. They have a subplanar top and, direct observations [10] detected steep and terraced slopes (Figure 4). This is the first time that these morphostructures, already identified by other authors [11], have been mapped in a sub-linear and sub circular trend. Such geomorphological elements are significant, from an ecological point of view, for structuring animal populations, as reported on the submerged itineraries map [12].
The 1:12,500 geological map of the Favignana and Levanzo Islands [4], shows part of the shoal's top, composed of dolomitic limestones and dolomites stromatoliti of Mesozoic, emerging above the mean sea level. These landforms ("i Pali") have a morphological convergence with Montagna Grande (the N-S oriented ridge above mentioned). They are made of the same lithology of Montagna Grande, and the slopes morphology look-like that of larger slopes of the ridge. Therefore, they probably represent a small remodelled part of this ridge in the underwater environment.

Depressions on sandy bottoms

The eastern coast of Favignana, from Cala Rossa to Cala Azzurra, is characterised by sandstone cliffs of about 10-15 meters height and a sandy sea floor up to ~20 m of depth (Figure 5). A detailed analysis of bedforms revealed a series of NNE-SSW elongated depressions sub-parallel to the coastline. The genesis of these morphotypes is not influenced by bottom currents or relict bedforms (i.e. natural origin), but by trawls towed during fishing activities that destroy the seagrass meadow, leaving depressions of different width and depth on the bottom. Therefore, such bedforms were attributed to Anthropocene [13; 14].
Another stretch where seafloor is covered by anthropogenic features is located just north of Favignana Village (north centre of the Island), at a depth of about 25m. The area was used for the "Tonnare", a network of several traps fixed to the bottom through large anchors and stand through the entire water column (from bottom to surface) with the aim of intercepting tunas and capturing them during the "*mattanze*" (tunas killing), activity which made this place famous all over the world. Their anthropogenic origin is demonstrated

extension between the Egadi and the coast of Trapani, DEM observation revealed several compromised areas and *intramatte*, especially between 5 and 20 m depth (Figure 7). Differences of submerged vegetation cover have been interpreted as morphological evidences of damage created by boats anchorages berthing inshore and grubbing up clods of meadows during the recovery. Further information can be obtained both analyzing spectral response from in-situ measurements (Figure 8) and using this data to improve the hyperspectral MIVIS image classification.

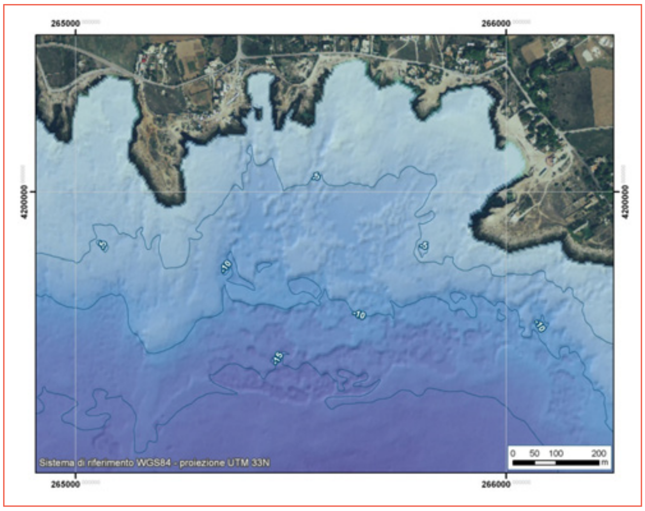

FIGURE 7 Example of Posidonia meadow damaged by anchors on the seafloor in front of Lido Ravine (southern sector of Favignana)

by visualisation of asymmetric and irregular profiles along orthogonal transects, which are highlighted by slope and lighting (Figure 6).

Intramatte

P. oceanica meadow characterizes the seafloor of the Egadi Islands. It is a priority habitat of the 43/92/EU Directive, abundant, well distributed and it is the most important biotic community. Despite the good preservation of the meadow, and its remarkable

Conclusions

The "shoals" observed in the south-central part of the island between 20 (top) and 50 m (base) depth are remains of the emerging part of the Mesozoic limestone-dolomite morphostructure forming the ridge of *Montagna Grande*. Some authors [15; 16; 17] have referred to basins and structural features formed during the Plio-Pleistocene extensional tectonic phase, which are emphasized by the submarine morphology. But what are the "shoals" (*I Pali*")? When did they form? What were they like during the Last Glacial Maxium (LGM)? Is their formation associated to faults, or are they morphological features related to selective erosion? Probably "*I Pali"* have been shaped by waves which have carved the slopes of these submerged rocks during the last Holocene sea level rise (and/or LGM sea level fall), as suggested by a series of erosion cliffs and

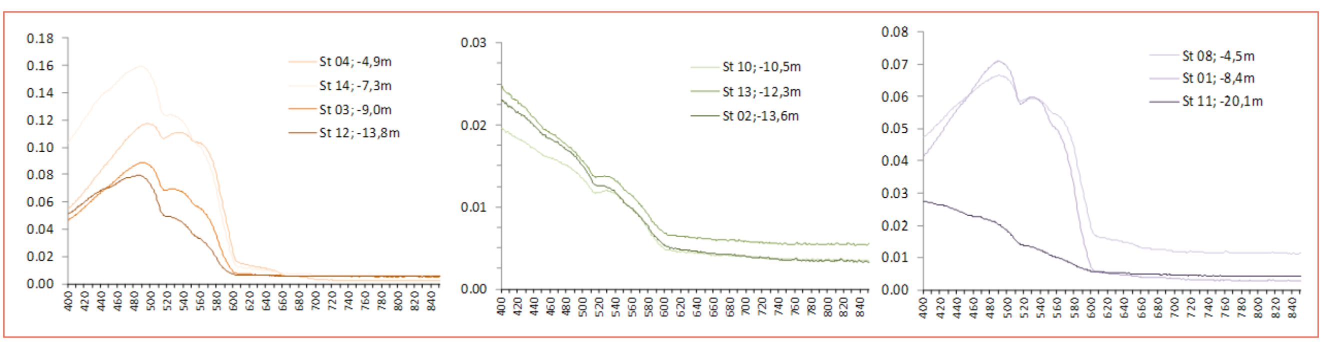

FIGURE 8 From left to right, examples of the in-situ spectral radiometry of the sandy seafloor, *P. oceanica* meadow and sandy seafloor with *P. oceanica*. The depth for each curve is recorded in the legend

wave-cut platforms. A second hypothesis explaining the morphological characteristics observed along the slopes of the paleo-stacks is a selective, polygenic erosion of low-angle carbonates and dolomites layers having different degree of erodibility. These processes occurred in the subaerial environment, before the last sea level rise and flooding, when these features were probably Island-detached from the shoreline (Cappucci *et al.*, in progress). Further study on detailed stratigraphic reconstruction, description of shapes and sizes (including the slope of the tested layer) may help to correlate this information with the tectonic movements and the rate of the sea level changes (Antonioli *et al.*, *pers. comm.*), but this study goes beyond the objectives of the present work.

Other bedforms, in particular *intramatte* and the depressions left by the action of trawling or anchors of tonnare have been dated as Anthropogenic features. An institutional timing for Antropocene should be established, during which humanity has become a major force of the Planet's geological transformation [18]. Man has changed the climate, leading to sea level rise, and has extensively contributed to mining activities. Actually, the presence of several quarries in Favignana is the evidence that the exploitation of natural resources started during the Roman Empire. Humans have shifted more sediment than all rivers combined together, and the present paper demonstrates how intensively the sea bed has been exploited, with a consequent heavy impact on the local ecosystem. Preliminary data processing and interpretation have allowed unpublished and detailed characterization of the seafloor along with the assessment of human impacts through a geomorphological and ecological analysis.

Detailed maps based on remote sensing data have been successfully created and, despite the lower resolution of DSM compared to other generated by using different data sources [19], they allowed to make many discoveries and conclusions. These maps could be used in the private sector for fishing, mining, and coastal management, as well as maritime uses planning (positioning of emerging technologies such as wind-wave power generation in particular). Legislators and stakeholders will also depend on these maps to support well-informed decision making on the use of natural resources. In particular, these data will allow the MPA management to implement and refine the ongoing protection actions and procedures for the preservation of the marine environment. The placement of anti-trawling bollards, the installation of moorings for buoys, and experimental measures for environmental requalification are aimed at encouraging greater tourist accommodation, in the framework of promoting sustainability and green economy [20].

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