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Geo-environmental cartography of the Marine Protected Area "Isola di Bergeggi" (Liguria, NW Mediterranean Sea)

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Abstract

Marine Protected Areas (MPAs) are considered one of the main tools for conservation, valorisation and management of coastal marine environments, and are defined by Italian Law (derived from European directives) as territories with "physical, geological, geomorphological and biological features having relevant naturalistic and environmental value". While the bionomic mapping of MPAs has received large attention by researchers, MPA geological or geomorphological cartographies have been seldom realized. In this study we present a geomorphological cartography, comprising also environmental themes having a geomorphological significance, realized in the MPA "Isola di Bergeggi".

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1. Introduction

Marine Protected Areas (hereafter MPAs) are considered one of the main tools for conservation, valorisation and management of coastal marine environments (Francour et al., 2001) and are currently the centre of scientific debate about their effectiveness (Jameson et al., 2002; Agardy et al., 2003; Guidetti et al., 2008).

Several international, national and local level laws (for a detailed synopsis see Dauvin et al., 2004) define MPAs as vehicles for promoting the long-term conservation of biodiversity and sustainable use of marine resources (Agardy, 1994). The Italian law 394/91 (Framework law on Marine Protected Areas), adopts the definitions of the EU directive 92/43 (Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora), thus defining MPAs as territories with values related to natural heritage, which is intended as "the sum of physical, geological, geomorphological and biological features having relevant naturalistic and environmental value". In the legislative context, the efforts are directed towards planning geomorphological conservation in the context of maintaining biological features. The knowledge base inside MPAs is usually developed in two stages: the first is an analysis of existing data, the second is the collection of field data, specifically for the representation of the sea floor.

Tricart and Kilian (1985) state that cartography is an essential tool to analyze the spatial aspects of natural environments. For this reason, environmental cartography is well developed in terrestrial protected areas, where it is aimed to assess territorial features and locate vulnerable areas in need of conservation (White et al., 1992). Maps in marine environments have similar purposes, but are far less common, both because of the reluctance to consider the sea as "territory" and the evident operational difficulties involved in mapping. In particular, Bianchi (2007) described the methods to obtain a series of baseline and derived environmental cartographies for the description and management of abiotic and bio-ecological features in marine protected areas. Along the Italian coastlines, efforts have been made to map bio-ecological features both at large (Bianchi et al., 1996; Relini et al., 2006) and small scale (Greco et al., 2004; Bianchi et al., 2006). For the 23 Italian MPAs, bio-ecological cartographies are available also in a number of unpublished charts drawn up for technical reports for their establishment. Modern cartographic tools (GIS software) are used inside MPAs to represent the distribution of natural features and to link them with other environmental features (Salm et al., 2000), to identify zones with different protection regimes (Villa et al., 2002), to analyze spatial relationships between habitats and zones (Fraschetti et al., 2005; Friedlander et al., 2007) and to identify potential networks of marine reserves (Leslie et al., 2003).

On the other hand, along the Italian inner continental platform there is a scarcity of maps related to abiotic (i.e. geological, geomorphological) features. The CARG (CARtografia Geologica) project of the Italian Geological Service foresees sixty five 1:50,000 sheets covering Italian marine coastal areas, of which only 35 have been or are being produced (August 2008: CARG, 2008). Detailed marine geomorphological studies have been carried out for some areas (e.g. Orrù and Ulzega, 1988; Orrù et al., 1994), however despite law 394/91 calling for the protection of both abiotic and bio-ecological features, geomorphological cartography is seldom used during the establishment of a MPA (e.g. Orrù and Pasquini, 1992).

Geomorphological cartography in marine environments assumes a particular importance because geomorphology affects habitat structure and functioning, defining the boundaries of ecosystems (Post et al., 2007) and provides a framework for the location of ecological processes (Olenin and Ducrotoy, 2006; Urban and Daniels, 2006). Moreover, geomorphic processes and landforms shape the distribution of biota, and conversely biota modify geomorphic processes and landforms (Stallins, 2006; Rovere et al., 2009a). Marine landforms are strictly related to the environment of formation and to the geological properties of the rock (e.g. karst caves in limestone cliffs). These two elements affect marine habitats: diverse lithologies are often characterized by different benthic populations (Guidetti et al., 2004) and particular landforms (e.g. caves or overhangs) provide the physical habitat to particular marine communities (e.g. caves and overhangs with *Parazoanthus axinellae* EuNIS code A4.712).

For this reason, marine geomorphological cartography should also include environmental and bio-ecological elements, derived from other studies. In this study we present the geo-environmental cartography developed for the "Isola di Bergeggi" MPA (Italy) and outline the main mapping methods employed to produce it. The area is located in the western part of the Liguria region (Italy, NW Mediterranean Sea) and has an area of 260 ha, one of the smallest Italian MPAs.

2. Study area

The continental shelf of the Ligurian sea can be divided into two parts: Alpine and Apenninic (Corradi et al., 1984). The division is made on a morphostructural basis: the Alpine margin is steep, with narrow shelves and cut by several canyons, whilst the Apenninic margin is wide, with well developed continental shelves and separated from the batial plain by a line of seamounts (Fanucci and Nicolich, 1984). In general, the coastal geomorphology of the region is represented by rocky shorelines interrupted at the main river mouths by coastal plains of limited extent (Fanucci et al., 1987). Thus, the continental shelves are characterized by lithologies with limited sedimentary deposits near the coast and Plio-Quaternary sediments further offshore (Bozzano et al., 2006).

The study area is comprised of an island ("Isola di Bergeggi"), facing cliffs of dolomitic limestone ("Punta del Maiolo"; "Punta Predani"; "Punta Grotte") (Figure 1), interrupted by pocket beaches. Near the pocket beaches, beach cliffs are cut by abrasion notches, while modern tidal notches and wave-cut platforms characterize the plunging cliffs (Rovere et al., In Press). The cliffs are also characterized by karst landforms, among which the most outstanding is the "Grotta Marina", a cave of karst origin successively shaped by marine erosion.

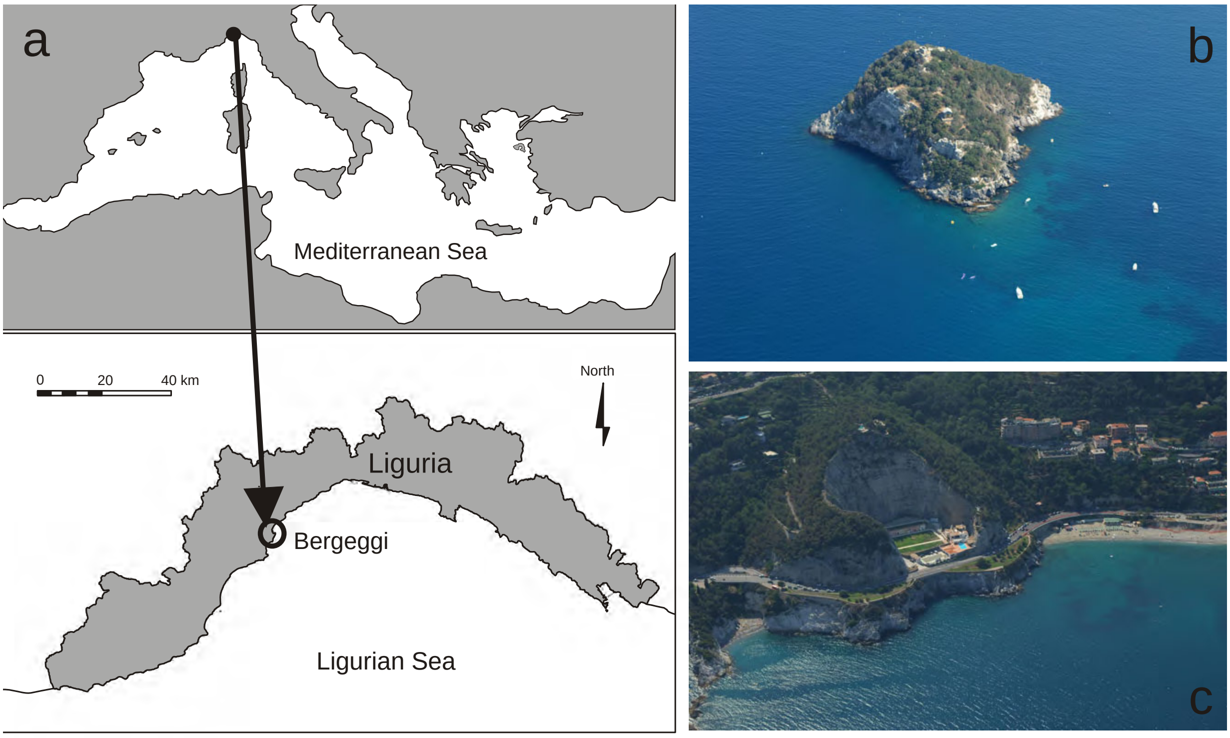

Figure 1. (a) Location of the study area; aerial oblique photos (provided by Regione Liguria) of (b) NW cliffs of the Bergeggi Island, (c) Punta Grotte cliffs, partially dismantled by quarrying activities.

3. Methods

Surveys have been carried out using both indirect and direct techniques (Figure 2). Indirect surveys included echosounding, side scan sonar, orthophotos and oblique aerial photos (provided by Ligurian Regional Authority). In coastal marine environments, indirect surveys should be supplemented with direct surveys in order to ground-truth aerial images and geophysical surveys, as well as provide detail for selected areas. Depth transects, underwater paths and punctual surveys have been carried out using SCUBA diving techniques (Colantoni, 2007). Depth transects consist of marked lines positioned on the bottom, along which the topography, relevant morphologies and types of sediments are measured. Underwater paths are similar to transects, except that they are completed without a reference line and the estimation of distances is performed using a Personal Diving Sonar (PDS) and compass. Punctual surveys are the simplest type of polygonal survey, a method that has proved efficient in mapping submerged shoals and caves (Colantoni, 2007).

Table 1 lists the main data that can be obtained from the survey techniques adopted, together with the related limitations. Additional data have been obtained from bibliographical resources (Table 2).

Survey technique	Positioning precision	Bat	Geo	Env	Main limits
Indirect					
Echosounding	GPS	✓			Information on the general morphology, but not on the geomorphology
Sidescan sonar	GPS	✓	✓		Ground truthing required for the interpretation of sonograms
Orthophotographs	GPS		✓	✓	Information on the upper limit of *P. oceanica* meadows, required for the ground-truthing of bathymetry
Perspective photographs	–		✓	✓	No correct positioning; required for ground truthing.
Bibliography	–	✓	✓	✓	Required ground truthing for the bibliographical data, particularly with respect to positioning
Direct					
Depth transects	GPS + diver	✓	✓	✓	Bathymetric precision limited by the diving computer (±0.5m)
Punctual surveys	GPS + diver	✓	✓	✓	Bathymetric precision limited by the diving computer (±0.5m)
Underwater paths	diver		✓	✓	Possible positioning errors, which do not allow bathymetric data to be obtained

Table 1. Techniques adopted for geo-environmental surveying, including the positioning precision, main data obtainable and limits. Bat = bathymetry data; Geo = geomorphological or sedimentological data; Env = environmental and/or bio-ecological data.

The information obtained from surveys and bibliography have been divided into nine main thematic issues:

- Topography: on-land contours were produced from Regione Liguria (Prot. 17393/808) digital terrain models (DTMs) at a spatial resolution of 5 metres. Beach contours were supplied by the Municipality of Bergeggi. Isobaths were obtained by interpo-

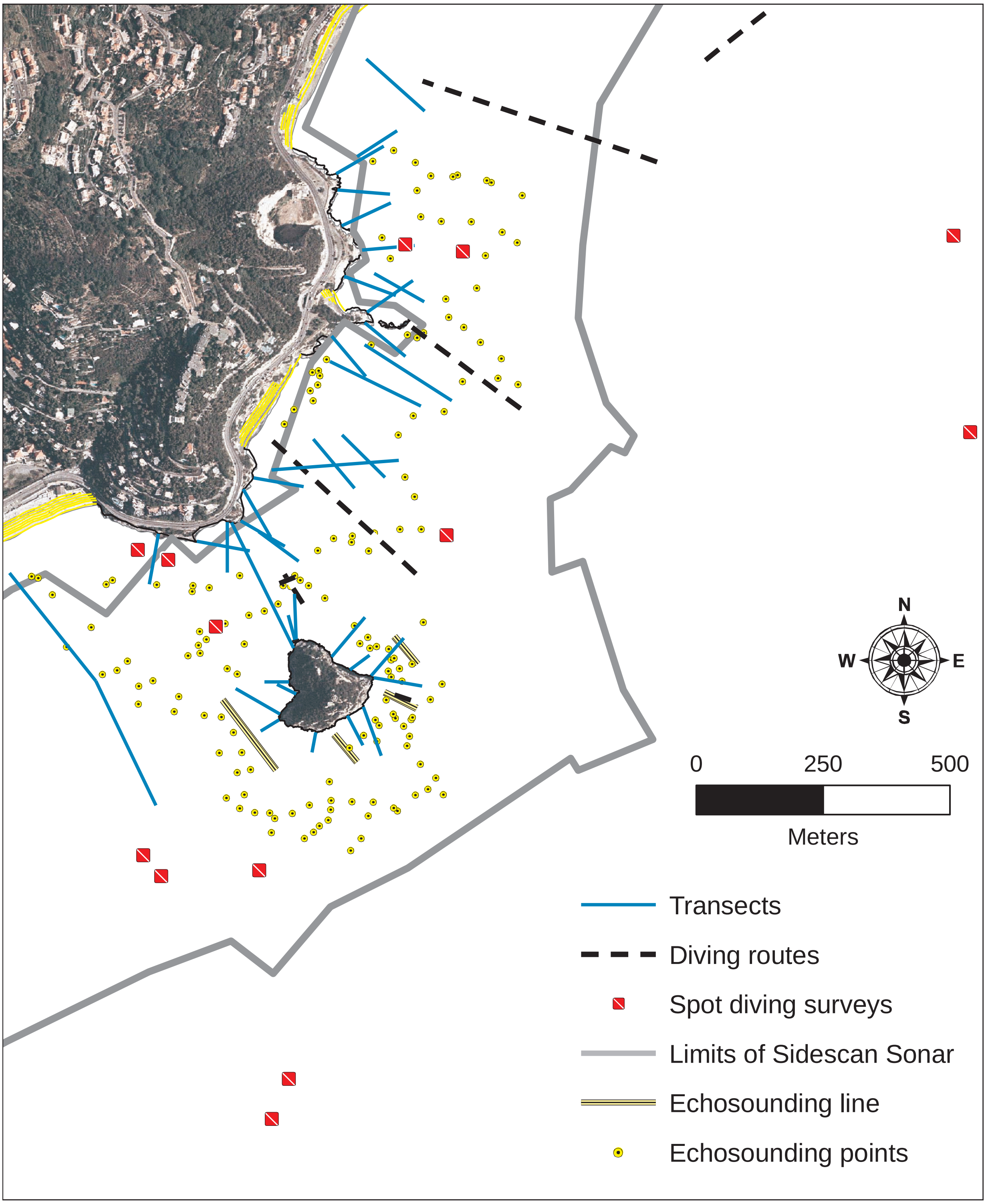

Figure 2. Direct and indirect surveys carried out in the study area.

Reference	Study object	Thematic issue
2, 4, 19, 31	Environmental quality	Ecological factors; Trends; Indicator species
4, 11, 34	Soft bottom biocoenoses	Ecological factors; Trends; Indicator species
4, 13, 14, 23	Hard bottom biocoenoses	Ecological factors; Trends; Indicator species
24, 26, 27, 28	Human impact on marine communities	Environmental alteration
29, 30, 31	Underwater geoheritage	Geoheritage elements
1, 5, 7, 9, 22, 25	Caves	Morphotypes; Landforms and deposits
6, 12, 20, 21, 32, 36	Seagrass meadows	Morphotypes; Landforms and deposits
8, 23, 33	Rocky shoals	Morphotypes; Landforms and deposits
10, 11, 14, 15, 16, 17, 35	Sedimentology	Morphotypes; Landforms and deposits
18	Submarine geomorphology	Morphotypes; Landforms and deposits

Table 2. Existing literature on the Bergeggi area, objective of the previous study and the thematic area where the information has been applied. References: 1. Alvisi and Colantoni (1994). 2. Asnaghi et al. (2009) 3. Bianchi et al. (2006). 4. Bianchi (2007). 5. Bianchi et al. (1988). 6. Bianchi and Peirano (1995). 7. Bianchi and Morri (1994). 8. BIOMAR (1985). 9. Carobene et al. (2004). 10. Cortemiglia (1991). 11. Damiani et al. (1989). 12. Diviacco and Coppo (2006). 13. Diviacco and Tunesi (1999). 14. Diviacco et al. (2000). 15. Fierro et al. (1975). 16. Fierro and Piacentino (1969). 17. Firpo et al. (1997). 18. Forti (1992). 19. Molinari and Diviacco (2003). 20. Montefalcone et al. (2009a;b). 21. Montefalcone et al. (2007). 22. Morri et al. (1994). 23. Parravicini et al. (2007). 24. Parravicini et al. (2008). 25. Parravicini et al. (2010). 26. Parravicini et al. (2009). 27. Parravicini et al. (2006). 28. Rovere et al. (2009a). 29. Rovere et al. (2008). 30. Rovere et al. (2009b). 31. Rovere et al. (2007). 32. Sandulli et al. (1994; 1998). 33. SEAWAY (1988). 34. Somaschini et al. (1998). 35. Tucci et al. (1995). 36. Vetere and Pessani (1989).

lating survey data (corrected for tide and atmospheric pressure at the time of sampling) and raw data provided by the Istituto Idrografico della Marina (Prot.SRE 1653). Despite the higher detail obtained from interpolating both the official bathymetric data and field data, instrument error should be taken into account. The depth gauges of modern diving computers are subject to an instrument error which is estimated at ±0.4-0.6 m (Figure 3).

- Marine Protected Area Zonation: the MPA zonation has been obtained through the coordinates contained inside the D.M. 07/05/07, Institution of the Marine Protected Area "Isola di Bergeggi".
- Morphotypes: a morphotype is defined as a seascape unit having similar geological, geomorphological or sedimentological features.

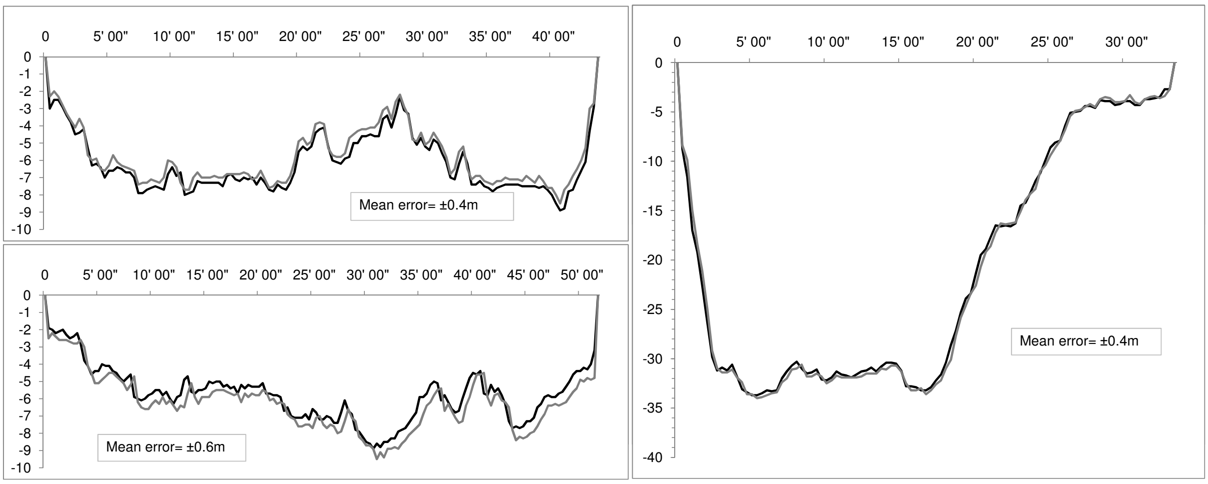

Figure 3. Diving profiles (depth vs dive time) of three different dives made during direct surveys using two different diving computers. Bathymetry accuracy is the mean of the differences between the two profiles.

- Landforms and deposits: areas considered landforms and deposits are those at a scale different to morphotypes (e.g. abrasion notches in cliffs, morphological relief).

- Ecological factors: the presence of bottom currents has been derived from the presence of species or facies linked to it (Pérès and Picard, 1964); in a similar way, the presence of indicator species provides information on the type and rate of sedimentation (Salen-Picard, 1993).

- Environmental alteration: the risk of alteration of the marine environment has been qualitatively evaluated. Evaluation has been performed by combining analysis of aerial and perspective photographs and technical reports (made available by Regione Liguria, http://www.ambienteinliguria.it/lirgw/eco3/ep/home.do) with direct surveys.

- Geoheritage elements: assessment of the underwater geoheritage was carried out using both indirect and direct surveys. The geoheritage elements identified can be ascribed to two main categories: scientific and additional (Rovere et al., 2010). The *scientific value* is calculated as the sum of the geomorphological significance that a process or landform may assume in terms of four subcategories: integrity, representativeness, rarity and paleogeography. *Additional value* refers to aspects that have a link with the process or landform, but that cannot be directly ascribed to the geomorphology. The subcategories identified for this value are: cultural, ecological, economic and aesthetical. These subcategories were described for terrestrial environments by Reynard et al. (2007).

- Trends: bioconcretion and sedimentary coverage have been identified on a physionomic basis. Benthic communities can enter phases of regression when a disturbance increases (Bellan et al., 1985).

- Indicator species: the presence of indicator species are reported on the map using a three letter code derived from the Latin name. The significance of an indicator species has been derived from literature on Mediterranean bionomy (Bianchi et al., 1993, and references therein).

4. Conclusion

Thematic environmental cartography has a primary role inside MPA studies, both for their knowledge and for their management. The cartography presented in this work allows the compilation of a baseline knowledge of the abiotic setting of the MPA, supplementing it with geomorphological environmental information. Due to the number of direct and indirect surveys carried out, the mapping developed is one of the most detailed geomorphological surveys completed for an Italian MPA, and the first obtained for a part of the inner continental platform of the Liguria Region. When integrated with information derived from bio-ecological and marine territorial cartography, the geo-environmental cartography presented here can be utilized as a tool for the management of the "Isola di Bergeggi" MPA. The final cartographic output allows the following general comments concerning geomorphological mapping inside MPAs:

1. Mapping was extended beyond the borders of the MPA in order to obtain data down to the shelf break, marking the transition between the continental shelf and the continental slope. This allowed the identification of several morphologically relevant areas, represented by zones of rocky outcrops, outside the MPA borders.

2. These above areas were identified after the zonation of the MPA and therefore constitutes a geomorphological basis for the future enlargement of the MPA.

3. Prior to the zonation of future MPAs, it is preferable that a consistent part of the continental shelf should be surveyed usig indirect surveys (e.g. multibeam sonar) in order to gather data on the shelf morphology. Using this data, direct surveys can be planned more efficiently.

4. The map presented in this study is characterized by themes which can change through time (e.g. shoreline extension, limits of marine phanerogams, human waste). Monitoring of an MPA is often considered from a bio-ecological perspective (e.g. evaluation of the protection effect on marine habitats), however this

rarely combines geomorphological considerations. MPA monitoring should also take into account any abiotic components.

Software

The map was created using ESRI ArcGIS 9.2 and the Spatial Analyst extension.

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