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Coastal and marine geomorphology between Albenga and Savona (NW Mediterranean Sea, Italy)

A. Rovere[a,b*], E. Casella[c,d], M. Vacchi[e], V. Parravicini[f,g], M. Firpo[c], M. Ferrari[c], C. Morri[c] and C.N. Bianchi[c]

[a]*Lamont Doherty Earth Observatory, Columbia University, Palisades, USA;* [b]*MARUM, University of Bremen & ZMT, Center for Tropical Marine Ecology, Bremen, Germany;* [c]*Department for the study of Territory, Environment and Life, DiSTAV, University of Genoa, Genoa, Italy;* [d]*Environmental Consulting, SEAMap ltd, Borghetto S.S., Italy;* [e]*Aix-Marseille Université, CEREGE CNRS-IRD UMR 34, Aix en Provence, France;* [f]*UR 227 CoReUs2, IRD (Institut de Recherche pour le Développement), Banyuls-sur-mer, France;* [g]*CESAB-FRB, Immeuble Henri Poincaré, Domaine du Petit Arbois, Aix-en-Provence Cedex 3, France*

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In this paper, we present a map describing the main geomorphological features of the coastal and marine area between the towns of Albenga and Savona (Ligurian Sea, NW Mediterranean) corresponding to a coastal stretch of ~40 km. To produce this map, we collated data from the literature, orthophotos, perspective photos, multibeam and side scan sonar data, and undertook direct surveys to ground truth data obtained using indirect techniques. We divided the information into nine thematic layers, including bathymetry, natural coastal types, geomorphological elements, seafloor coverage (both geological and biological), coastal and nearshore dynamics, human influence on coastal and marine environments, coastal occupation and protected areas.

Keywords: marine environment; coastal geomorphology; marine habitats; Mediterranean Sea; seafloor mapping

1. Introduction

The inner continental shelf has a particular importance in the framework of coastal management, as it represents the boundary between the coastal zone, usually highly influenced by human activities, and the open ocean (Royo, Silvestri, Pergent, & Casazza, 2009). For this reason, the inner shelf is considered that part of the marine environment most prone to human-induced alterations and impacts, and is the zone where the greatest conservation and management efforts are usually directed (Parravicini et al., 2012).

Cartography is an essential tool to help implement management and conservation efforts both in marine (Bianchi, Parravicini, Montefalcone, Rovere, & Morri, 2012; Brenner, Jiménez, & Sardá, 2008; Ramírez-Sanz, Alcaide, Cuevas, Guillén, & Sastre, 2000; Rovere et al., 2013; Rovere, Parravicini, Firpo, Morri, & Bianchi, 2011) and terrestrial environments (Martínez-Graña, Goy, Zazo, & Yenes, 2013). Cartography not only represents the spatial location of marine habitats and

*Corresponding author. Email: rovere@ldeo.columbia.edu

geomorphic features (Miccadei, Orru, Piacentini, Mascioli, & Puliga, 2012; Rovere et al., 2010; Sardá, Rossi, Martí, & Gili, 2012), but also allows, through the use of geographic information systems (GIS), the modeling of different management scenarios (Fraschetti et al., 2005; Montefalcone et al., 2013; Parravicini et al., 2012; Vassallo, Paoli, Rovere, & Montefalcone, 2013). Mapping of terrestrial information is largely reported in the literature (Finn, 2011; López-García & Guzmán, 2010; Rose & Smith, 2008; Sahlin & Glasser, 2008), and takes advantage of numerous survey techniques such as satellite imagery, aerial photos, LIDAR or high-accuracy GPS (Bowles & Cowgill, 2012; Palamara, Dickson, & Kennedy, 2007; Storrar, Stokes, & Evans, 2013). On the other hand, underwater mapping require greater survey efforts, which often translate into higher costs per area unit (Bianchi et al., 2004; P. G. Finn, Udy, Baltais, Price, & Coles, 2010).

The high costs to acquire accurate data for the inner continental shelf are usually faced by regional or national authorities, which either focus their attention on specific themes, often in restricted areas (i.e. the study of protected habitats, or particular geomorphic features, Rovere, Vacchi, Firpo, & Carobene, 2011), or demand for detailed data in the framework of environmental impact assessment for coastal and marine infrastructure (Gatti et al., 2012). This often leads to fragmentary information, mapped at different scales, with different purposes and by different public or private entities. From the perspective of integrated coastal zone management, such a situation leads to the conundrum of 'much information, poor usability'.

This is also the case of the Liguria Region, Italy, NW Mediterranean, where a good amount of data is available both from the literature and from official regional authorities, but is sparse among published literature and technical reports by different authorities. In this study, we mapped all the information available in the coastal area between Albenga and Savona (in the western coast of Liguria Region) and completed it with a direct survey on the continental shelf. We present the results of our work in1:10,000 geomorphological map.

2. Study area

Our study area includes the inner continental shelf and coastline between the towns of Albenga and Savona (Ligurian Sea, NW Mediterranean). In general, the coastal setting of the region is represented by rocky shorelines interrupted at the main river mouths by coastal plains of limited extent (for synopses of local studies in the Ligurian region, see Balduzzi et al., 2008; Bianchi, Morri, Peirano, Romeo, & Tunesi, 1987; Bozzano, Corradi, Fanucci, & Ivaldi, 2006; Relini & Bianchi, 1988; Rovere, Vacchi et al., 2011; Vietti et al., 2010).

The area between the towns of Albenga and Loano (about 31 km west of Savona) is the largest coastal plain in Liguria (Balduzzi et al., 2008), and is fed by various watercourses. The sedimentary deposits, before prograding offshore, fill a tectonic trough in the substratum (half graben) (Fanucci, Fierro, Gennesseaux, Rehault, & Tabbo, 1974), and the width of the continental shelf is strictly dependent on the size of the trough filled. In this sector the continental shelf is comparatively wide and regular. From Loano to Savona, both the coastal plains and the continental shelf are narrower. The shelf has a steeper slope (Fanucci, Fierro, Firpo, Mirabile, & Piccazzo, 1979), and is cut by three major canyons. As regards lithology of rocky shorelines, they are characterized by sandstones and carbonate rocks. Along some tracts, igneous rocks, metamorphic rocks and shists outcrop (Rovere, Vacchi et al., 2011).

3. Methods

3.1. *Surveys and literature data*

In this study, we mapped the coastal area and the inner continental shelf between Albenga and Savona using raw data from Regional, Provincial and National Authorities interpreted in light of original direct surveys carried out by the University of Genoa in the course of different research projects in the period 2005–2012. Figure 1 and Table 1 present a summary of the type of data available and the different survey techniques employed, along with the scale and the different thematic layers represented on the map.

The marine area has been mainly mapped extracting information from Side Scan Sonar, Multibeam and Echosounding datasets, which were ground-truthed with information obtained from direct surveys. Direct surveys have been carried out using SCUBA diving and snorkeling techniques (Bianchi et al., 2004; Rovere, Parravicini et al., 2011; Vacchi, Rovere, & Schiaffino, 2012).

In order to complete the information obtained from surveys, we included in the map information derived from other sources. This information has been collected from both maps published in scientific papers and from official datasets published in the webGISs of National or Regional Authorities (www.pcn.minambiente.it; www.ambienteinliguria.it). The information from the scientific literature was often available in the format of raster maps that have been digitized and georeferenced before elements of interest could be digitized. Instead, data from official webGISs was available either for download or as a WMS service.

3.2. *Mapped layers*

The mapped information has been divided into base layers and nine thematic layers. Hereafter we describe how we built each layer.

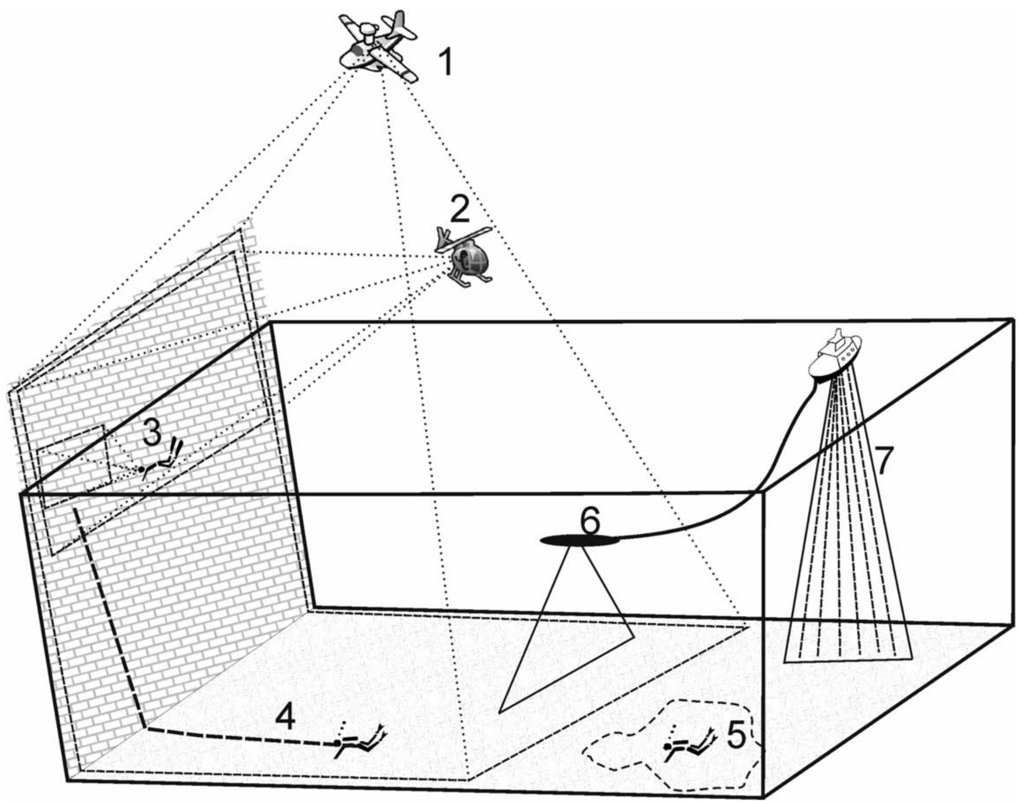

Figure 1. Survey techniques used in this work. 1 = Orthophotos; 2 = Perspective photographs; 3 = Snorkeling surveys; 4 = Transects; 5 = Spot diving surveys; 6 = Side scan sonar; 7 = Multibeam or Echosounding.

Table 1. Data used to build the maps presented in this study.

Type of data	Source	Scale	Type of information 1	2	3	4	5	6	7	8	9
Side scan sonar	Regione Liguria	1:5000			×	×	×		×		
Multibeam	Provincia di Savona, Autorità Portuale di Savona,	1:5000	×		×	×	×		×		
Bathymetric points (echosounding)	Istituto Idrografico della Marina, concession N. 1653	1:10,000	×								
Orthophotos	Italian National Cartographic portal (www.pcn.minambiente.it)	1:5000		×		×			×	×	
Perspective photos	Regione Liguria	Not in scale		×					×	×	
Official cartography of Regione Liguria	Regione Liguria, www.ambienteinliguria.it, SICOAST.	1:10,000				×	×	×	×		
OffIcial cartography of the Ministry of Environment	www.pcn.minambiente.it	1:10,000									×
Direct surveys	This study	1:1000			×	×	×		×		
Local studies on coastal erosion	Fierro, Berriolo, and Ferrari (2010), Fierro and Piacentino (1969), Firpo et al. (1997)	Variable, 1:2000 to 1:5000						×	×		
Local studies on marine environment	BIOMAR (1985), Diviacco and Coppo (2006), Diviacco, Tunesi, Ianniruberto, and Piccione (2000), Parravicini et al. (2009; Parravicini, Thrush, Chiantore, and Morri, (2010); Rovere et al. (2008); Rovere et al. (2010); SEAWAY (1988)	Variable, 1:2000 to 1:50,000			×	×	×		×		

The numbers in the field ‘Type of information refer to the different themes identified in the map legend. 1 = Bathymetry; 2 = Natural coastal types; 3 = Geomorphological elements; 4 = Seafloor coverage (geological elements); 5 = Seafloor coverage (biological elements); 6 = Coastal and nearshore dynamics; 7 = Human influence on coastal and marine environments; 8 = Coastal occupation; 9 = Protected areas.

Base layers. These represent layers that are used as a background for the map. In our case, the base layers represent the background for the inland areas, which are not covered by the mapped information. To represent terrain, we used shaded relief elevation data obtained from the Digital Terrain Models of Regione Liguria (Concession N. 17393/808) with a spatial resolution of 5 m. We overlaid this layer with Open Street Map (http://www.openstreetmap.org) to represent the geography of the inland parts of the map.

1 **Bathymetry**. Isobaths were obtained by interpolating the XYZ data provided by the Istituto Idrografico della Marina (Concession N. 1653) and multibeam data (Table 1). We obtained

a 5 × 5 m GRID file from which we interpolated 5 m contours down to of −50 m and then 10 m contours below this depth.

2 **Natural coastal types**. We identified natural coastal types from orthophotos (Table 1). We supported our interpretation with perspective photos, which in some cases are more useful to discern between coastal types. As an example, we used perspective photos to discern between the different types of rocky coasts. It is worth noting that the study area is microtidal, so it was not possible to recognize and map hightide and lowtide lines on the map.

3 **Geomorphological elements**. This layer represents those themes, points or lines, representing landforms and deposits characterizing at medium-to-small scale the marine bottom and submerged coastal areas. These have been identified mainly on the basis of direct surveys and, in some case, with the aid of orthophotos and perspective photos. Larger-scale morphological elements have been interpreted using bathymetric data.

4 **Seafloor coverage (geological elements)**. In this layer, we identify the sedimentary and bedrock characteristics of the seafloor. We defined sediment type and presence of bedrock/beachrock using Multibeam, Side Scan Sonar and our direct surveys. Where information was not available, we completed the map using information from the literature (Diviacco et al., 2000, Firpo et al., 1997, BIOMAR, 1985; SEAWAY, 1988). Beachrocks were mapped using orthophotos.

5 **Seafloor coverage (biological elements)**. In this layer, we represented the main biological elements that are relevant from a geomorphological perspective. *Posidonia oceanica* seagrass meadows, dead matte of *P. oceanica*, and the mix of *P. oceanica* and dead matte have been mapped starting from the regional atlas by Diviacco and Coppo (2006) derived from previous works (Bianchi & Peirano, 1995) and Side Scan Sonar data. We updated the 2006 work by Diviacco & Coppo using Multibeam data and our direct surveys. The distribution of Coastal detritic bottoms ('Mediterranean animal communities of coastal detritic bottoms', EuNIS code A5.46) has been derived from direct surveys and Side Scan Sonar data.

6 **Coastal and nearshore dynamics**. The net longshore transport and sediment input have been derived from the literature (Fierro et al., 2010; Fierro & Piacentino, 1969; Firpo et al., 1997). The limits of physiographic units have been derived from official data by Regione Liguria (www.ambienteinliguria.it). A physiographic unit is a littoral area (emerged and submarine) inside which beach sediments are confined and no sediment exchange occurs with the physiographic units nearby. The limits of a physiographic unit are natural or artificial structures reaching depths similar to the depth of closure of the beach, or that invert the direction of the longshore transport. The physiographic units have been defined at regional scale by the Ligurian Regional Authority, and are being actively used for coastal management and planning (e.g. in the planning of beach nourishment). The erosional/progradational trends for beaches in the study area have been derived from the SICOAST of the Regione Liguria (www.ambienteinliguria.it). SICOAST is a webGIS which collates information on the coastal area of the Region. Among the data available in SICOAST is the position of the coast from 1944 to 2003. In order to infer the long-term evolution of the coastal area, we compared the 1944 and 2003 positions of the shoreline and, with a buffer tolerance of 2 meters, detected which was more advanced. If the 1944 shoreline was seaward with respect to the 2003 shoreline, it was shown as 'beach erosion' and vice versa for 'beach progradation'. Where the two shorelines were closer than 2 meters, we considered it 'stable', and represented it with the symbol 'beach' in the 'Natural coastal types' layer.

7 **Human influence on coastal and marine environments**. In this layer human artifacts affecting the coastal and marine environment from a geomorphological perspective are

recorded. Recent beach nourishment (2003–2007) has been obtained from official Regional data (www.ambienteinliguria.it); anchoring, diving sites and shipwrecks have been obtained through direct surveys, perspective photos and bibliographic sources (BIOMAR, 1985; SEAWAY, 1988). The presence of coastal defenses, such as groynes, jetties or harbors, has been digitized from orthophotos. Dates of mussel harvesting have been placed on the map according to bibliographical information (Parravicini et al., 2009; Parravicini et al., 2010; Rovere et al., 2008), while sewage pipes and other structures on the seafloor have been digitized from Regional datasets (www.ambienteinliguria.it).

8 **Coastal occupation**. We used orthophotos and perspective photos to map the occupation of the coast by urbanization or infrastructure, here intended as railroads and roads. We divided the coastal occupation layer in to two parts, one representing the presence of coastal occupation 50–100 m from the modern shoreline, the other representing it at less than 50 m from the shoreline.

9 **Protected areas**. The presence of protected areas (marine Sites of Comunitary Interest and Marine Protected Areas) has been downloaded from the Italian National Cartographic Portal (www.pcn.minambiente.it).

4. Discussions and conclusions

In our study, we mapped the Albenga-Savona area using a range of techniques and data. The cartography presented in this work represents the most comprehensive spatial database available to date. As attached material to this publication we provide not only the map (Main Map) but also the native shapefiles and graphic layer files and the ArcGIS symbology ('see underlying research materials), in order to encourage their use for management activities or for using the symbology for other maps. We also include a KML file containing field pictures in order to provide supplementary information to the reader on our cartographic choices.

In our map we merged data from different sources, at different scales (Tab.1). The choice of 1:10,000 for our final map is dictated by the resolution of the majority of the available datasets, which have been compiled at this scale or at a better resolution. Despite the choice of a unique scale, it is evident from the distribution of our surveys (see inset maps in the Main Map and supplementary KML file) that the coastline and the part of the inner continental shelf above −30 m are richer in information. Information below −30 m relies on smaller-scale maps, detailed by fewer surveys.

This is because of the greater accessibility of shallow water environments for surveys and the usability of remote sensing techniques (e.g. orthophotos and perspective photos) to map some aspects of shallow water environments (e.g. the upper limit of seagrasses). It is worth noting that such a situation is common to several, if not all, coastal areas. The fact that map accuracy decreases with depth should be taken into account or at least discussed for any coastal and inner shelf map.

There is another aspect that must be considered in the discussion of map accuracy. In our area, we were able to map the emerged coastal part of our study area at the same scale using available datasets. For the marine area, we highlight that environmental and commercial interests have driven marine data acquisition along the area between Albenga and Savona, creating discrepancies in data coverage. Specifically, the areas of Isola di Bergeggi (a Marine Protected Area), Isola Gallinara (where there is the possibility to establish a marine Protected Area) and Capo Noli (Site of Comunitary Interest) have been the target of several Side Scan Sonar, Multibeam and direct survey campaigns to assess natural heritage value. Vado Ligure has recently been the focus of studies due to an Environmental Impact Assessment of the enlargement of the commercial harbor.

The map we present here has many aspects that relate to coastal management activities. As an example, the updated cartography of *Posidonia oceanica* and associated habitats is an essential tool for coastal development plans, as this habitat is among the priority habitats of the Habitat Directive (92/43/EEC), and any new infrastructure potentially harming the marine environment must assess the impacts on this habitat. From the perspective of coastal dynamics and human influence on coastal and marine environments, the map collects all the available information on these two aspects, and can be used to direct specific management activities and studies, such as for example the removal of human-made waste on the bottom or evaluation of damages to marine ecosystems caused by anchoring. The distance of coastal occupation from the shoreline, unified with the information on the long-term coastal dynamics trend, gives important insights on sensitivity of infrastructure to coastal erosion and sea level change.

The underlying research materials for this article can be accessed at <http://coastalgeomorphology.org/coastalgeomorphology/>

Software

The maps here presented were created using ESRI ArcGIS 10.2.

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