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Seabed classification around Lampione islet, Pelagie Islands Marine Protected area, Sicily Channel, Mediterranean Sea

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ABSTRACT

We present the first seabed map of the shallow-water areas of Lampione, the islet of the Pelagie Islands Marine Protected Area (Sicily Channel, Italy). The seafloor was mapped from the coast to a depth of about 75 m, using high-resolution multibeam systems (both for bathymetry and backscatter) along with ground-truth data in the form of grab samples and ROV video-observations. By integrating these original data, a first seabed classification was produced through the use of the Remote Sensing Object Based Image Analysis, a semi-automatic segmentation approach. The resulting 1: 5,000 scale map includes sediment types and habitat distribution contributing to the knowledge of the peculiar marine ecosystem observed at Lampione. In particular, the map provides the first indication of the wide occurrence of rhodolith/maërl habitats at Lampione, which are among the most important ecosystems in the Mediterranean Sea.

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Multibeam bathymetry; backscatter; RSOBIA; ROV video-observations; grab samples

1. Introduction

Marine Protected Areas (MPAs) are left in their natural state to preserve biodiversity and protected species (De Luca et al., 2018) and play a key role in the promotion of the suitable use of marine resources and ecological conservation (Agardy, 1994). The European Framework and national laws award protection to these particular areas by imposing measures to monitor the environmental status of such areas (e.g. Guidetti et al., 2008; Pieraccini, Coppa, & De Lucia, 2016). In this context, The Pelagie Islands Marine Protected Area (Sicily Channel, southern Mediterranean), characterized by different geological features associated with specific biological communities, launched a project to assess the conservation status and map the distribution of *Posidonia oceanica* (L.) Delile meadows and coralligenous habitat (Innangi et al., 2018; Tonielli et al., 2016). These have been recognized as VMEs (Vulnerable Marine Ecosystems) by the EU and other official environmental commissions (<http://www.fao.org/in-action/vulnerable-marine-ecosystems/en/>; e.g. Bensch, Gianni, Greboval, Sanders, & Hjort, 2009; Bernal, 2016; Francour, Magréau, Mannoni, Cottalorda, & Gratiot, 2006; OCEANA, 2009). Previous investigations were carried out to study the two main islands of the Pelagie MPA, namely Lampedusa (Tonielli et al., 2016) and Linosa (Innangi et al., 2018), while Lampione, the islet of the MPA, has not been investigated yet. During ‘BioGeoLin 2017’ survey, both MultiBeam Echo Sounder (MBES) and ground-truth data were acquired around this islet,

showing the occurrence of rhodolith/maërl beds (as well as the presence of seagrasses), up to now only hypothesized on the base of predictive modeling by Martin et al. (2014). Coralligenous habitats and rhodolith/maërl beds are considered to represent a typical underwater seascape and a biodiversity hotspot in the Mediterranean Sea (Barbera et al., 2003; Birkett, Maggs, & Drig, 1998; Bonacorsi, Pergent-Martini, Clabaut, & Pergent, 2012; European Parliament & Council of the European Union, 2008; UNEP-MAP-RAC, 2008). They occur on the seafloor between –20 and –120 m and consist of biogenic concretions, mainly produced by the accumulation of calcareous encrusting algae (mostly Corallinaceae but also Peyssonneliaceae) that develop under dim light conditions and high-energy marine currents (Barbera et al., 2003; UNEP-MAP-RAC, 2008). Although these calcareous bio-concretions (coralligenous and rhodolith beds) are considered well represented in the Mediterranean Sea, their real range of distribution is not well known yet (Agnesi et al., 2009). So, the data acquired have been used to draw a preliminary seabed map of Lampione, through the use of Remotely Sensing Object Based Image Analysis (RSOBIA; Le Bas, 2016), also applied at Lampedusa and Linosa (Innangi et al., 2018). This tool is an object-image analysis application integrated into ESRI’s ArcMap GIS, as an objective and quantitative method to interpret geophysical data images (acoustic backscatter mosaic and bathymetric data), to infer physical, geological and biological proprieties of the

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seafloor, such as surface roughness (e.g. Fonseca & Mayer, 2007; Fonseca, Brown, Calder, Mayer, & Rzhonov, 2009), sediment grain size (Bentrem, Avera, & Sample, 2006; Brown & Blondel, 2009; Collier & Brown, 2005; De Falco et al., 2015; Innangi et al., 2015, 2016; Lo Iacono et al., 2008), distribution of seagrass meadows (e.g. De Falco et al., 2010; Micallef et al., 2012; Tonielli et al., 2016) and coralligenous habitats (e.g. Bonacorsi et al., 2012; Bracchi et al., 2015; Bracchi, Basso, Marchese, Corselli, & Savini, 2017).

2. Study area

Lampione is an islet belonging to the Pelagian Archipelago in the Sicily Channel (Italy), formed also by Lampedusa and Linosa islands (Figure 1). The Sicily Channel is an epicontinental sea, with average depth of less than -400 m, locally interrupted by deep, tectonically-controlled, NW-SE oriented troughs (Pantelleria, Malta and Linosa grabens; Civile et al., 2010; Grasso et al., 1991; Lanti, Lanzafame, Rossi, Tranne, & Calanchi, 1988; Figure 1). The area was affected by crustal stretching in the Neogene-Quaternary, giving place to an intraplate rift system and volcanism at Pantelleria and Linosa (Civile et al., 2010 and references herein; Lentini, Carbone, Catalano, & Grasso, 1995). This study focuses on Lampione ($35^{\circ}33'00''$ N – $12^{\circ}19'11''$ E), an islet located 17 Km off the NW coast of Lampedusa and 110 Km off Tunisia, with a surface of 0.021 km², 750 m of coastal perimeter and a maximum elevation of 36 m a.s.l. (Figure 1). The morphology of Lampione is characterized by the occurrence of a flat

top which gradually slopes to the East, while the western side is a vertical cliff. It reflects the structure of a gently SE-dipping, shallow-marine carbonate platform (Grasso & Pedley, 1985) being part of the WNW-ESE oriented ‘Lampione-Lampedusa high’ of structural origin, i.e. an uplifted block (Torrelli, Grasso, Mazzoldi, Peis, & Gori, 1995). Lampione is entirely calcareous, with a dolomitized carbonate succession composed of mudstones, wackestones and packstones referred to the ‘Halk el Menzel Formation’ (Tunisian off-shore, 46–34 Myrs BP; Bonnefous & Bismuth, 1982; Grasso & Pedley, 1985; Lo Cascio & Pasta, 2012).

The Sicily Channel is a high-energy site with a dynamic and highly variable current system that exchanges waters between the Western and Eastern Mediterranean Basins. In particular, a water mass (about 200 m thick) of Modified Atlantic Mediterranean Water (MAW) flows eastward, (Figure 1, inset) and, after entering the Sicily Channel, splits into two main branches, the Atlantic Ionian Stream (AIS) and the Atlantic Tunisia Current (ATC), the latter moving through the Pelagian Archipelago (Figure 1; Astraldi, Gasparini, Gervasio, & Salusti, 2001; Poulain, Menna, & Mauri, 2012). This complex circulation pattern, together with bottom structures such as seamounts, banks, volcanoes, pockmarks and steep-walled basins, are the main factors responsible for the biodiversity richness of the Sicily Channel, where healthy deep coral communities find favorable habitat and several pelagic species such as anchovies, bluefin tuna and fin whales have spawning and feeding areas (UNEP-MAP-RAC, 2015).

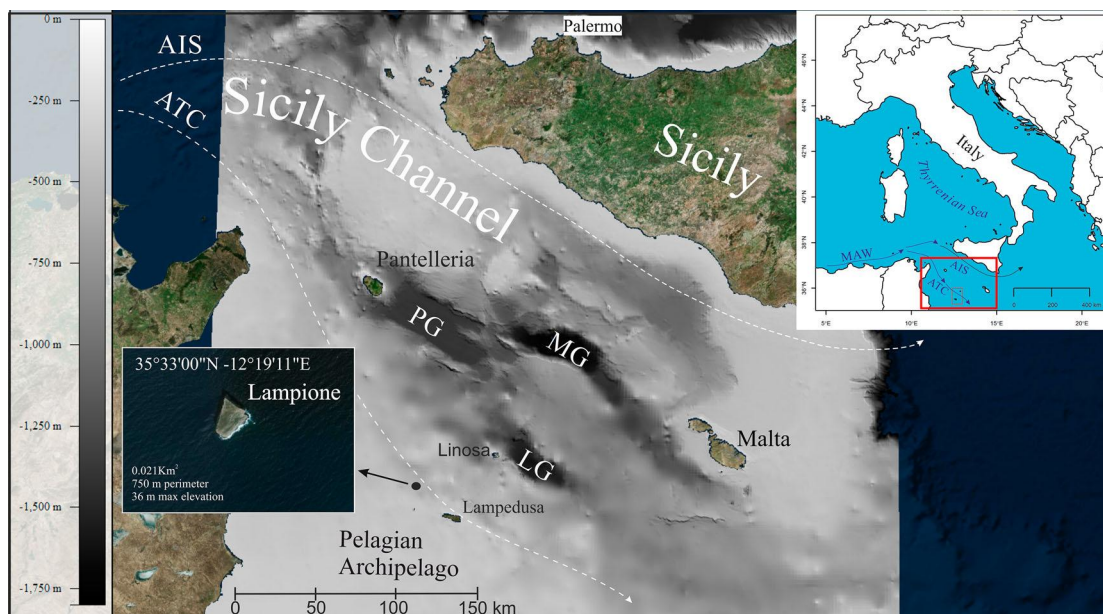


Figure 1. Location Map of Lampione Islet in the Sicily Channel (Central Mediterranean Sea, Italy). Bathymetry is taken from EMODnet portal (<http://www.emodnet-bathymetry.eu/data-products>); the Pantelleria graben (PG), the Malta graben (MG), and the Linosa graben (LG) are the principal tectonic depressions of the Sicily Channel. The Atlantic Ionian Stream (AIS) and the Atlantic Tunisia Current (ATC) are shown (The MAW flows is shows in inset).

3. Methods

3.1. Acoustic data acquisition and processing

Geophysical data were collected by the Institute for Coastal Marine Environment (IAMC, now ISMAR, Institute of Marine Sciences) of the National Research Council (CNR) of Naples (Italy) during the oceanographic survey ‘BioGeoLin 2017’ (8–20 September 2017), onboard the R/V *Minerva UNO* (Di Martino et al., 2017). Multibeam bathymetric survey (Figure 2) were carried out around Lampione Islet from 15 m to 75 m of depth, obtaining the whole coverage of shallow-water areas, also outside the boundaries of the MPA. The survey was performed using a pole-mounted Teledyne Reson SeaBat 7125 400 kHz MBES (Innangi et al., 2018), providing sub-centimetric resolution in the bathymetric data at that depth range (grid 1×1 m). The vessel was equipped with an Omnistar Differential Global Positioning System (DGPS) and an IxSea Octans 3000 that provided positioning data (with sub-meter accuracy) and attitude data (0.01° accuracy) to the navigation software. A Valeport mini-SVS sound velocity probe was installed

near the transducer, thus providing the real-time surficial sound speed for the beam steering, and a sound velocity profiler was systematically lowered through the water column to get the velocity profile required for depth computation. The Teledyne PDS 4.1 software was used for logging and processing MBES bathymetric data. Data de-spiking was carried out manually without the application of automatic filters in order to preserve data accuracy and resolution. The Teledyne Reson 7125 MBES is also able to collect backscatter intensity (the measurement of sound scattered back toward the transmitter by acoustic reflection and scattering) as Snippet data (De Falco et al., 2010; Innangi et al., 2015; Lurton et al., 2015; Parnum & Gavrilov, 2011). Snippet data processing was carried out using FMGeocoder Toolbox (FMGT) in Fledermaus 7.6 version (QPS, 2016). These data were corrected for receiver gain, transmit power, transmit pulse width, spherical spreading, attenuation in the water column, area of ensonification, beam pattern, speckle noise and, finally and most importantly, for angular dependence and local slope (Mallace, 2012; QPS, 2016). The final mosaic was exported as a geo-referenced TIFF image

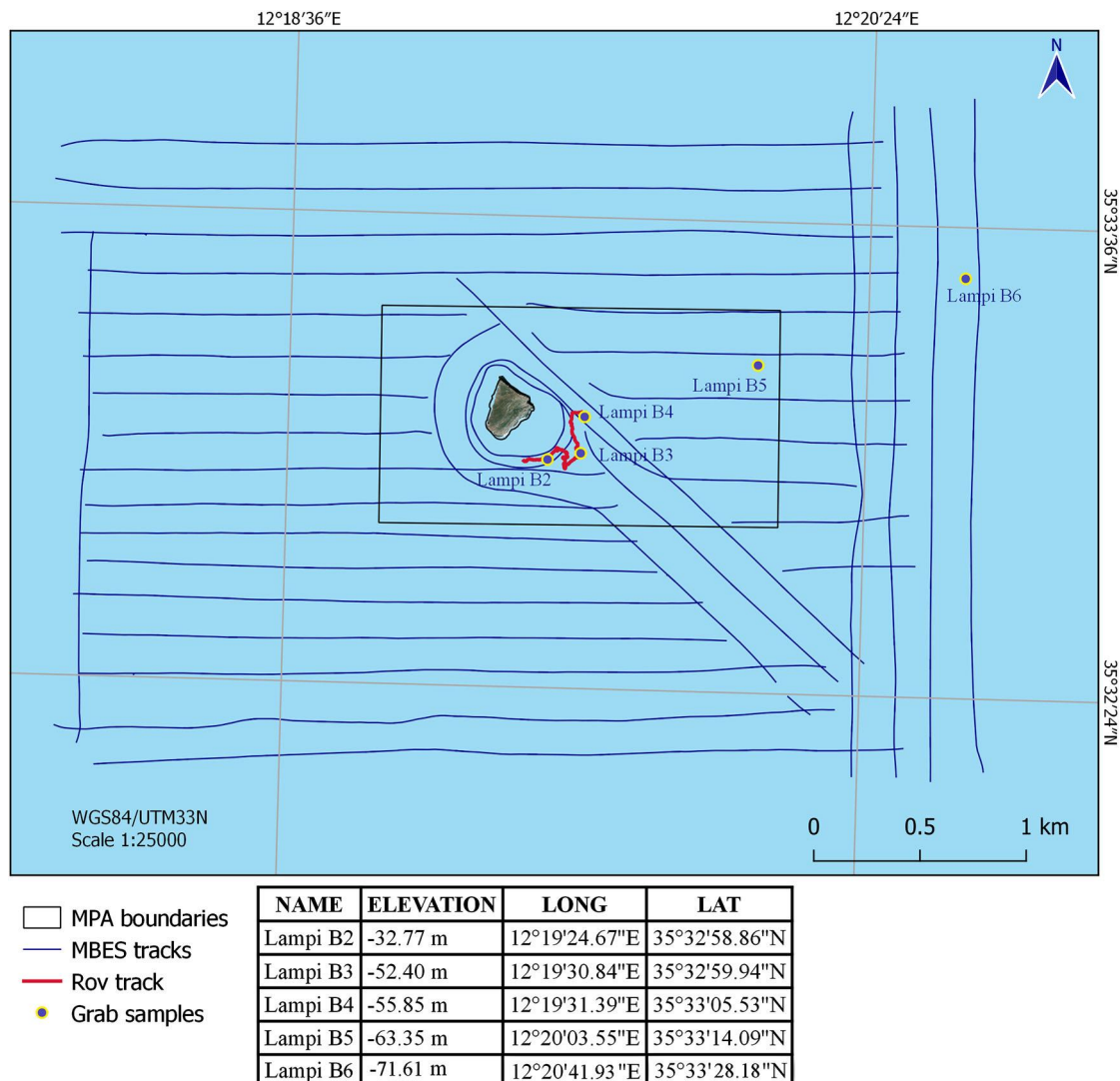


Figure 2. MBES navigation lines around Lampione and positions of collected ground-truth data.

with a 1 m pixel size and imaged using a gray scale in which the higher backscatter values correspond to darker areas. A range of signal values in relative (dB) units ranging from -60 dB (lighter tones, corresponding to low backscatter) to -25 dB (dark gray tones, considered as high backscatter) was adopted in the maps. The MBES used for this study was not calibrated to obtain absolute backscatter levels. Consequently, backscatter data presented cannot be compared with absolute values reported in other studies, as in De Falco et al. (2010), but this kind of data is used in a relative way for semi-automated acoustic seabed classification, being locally calibrated with ground-truth information (see section 3.2 and 3.3; see also Innangi et al., 2018).

3.2. Ground-truth information

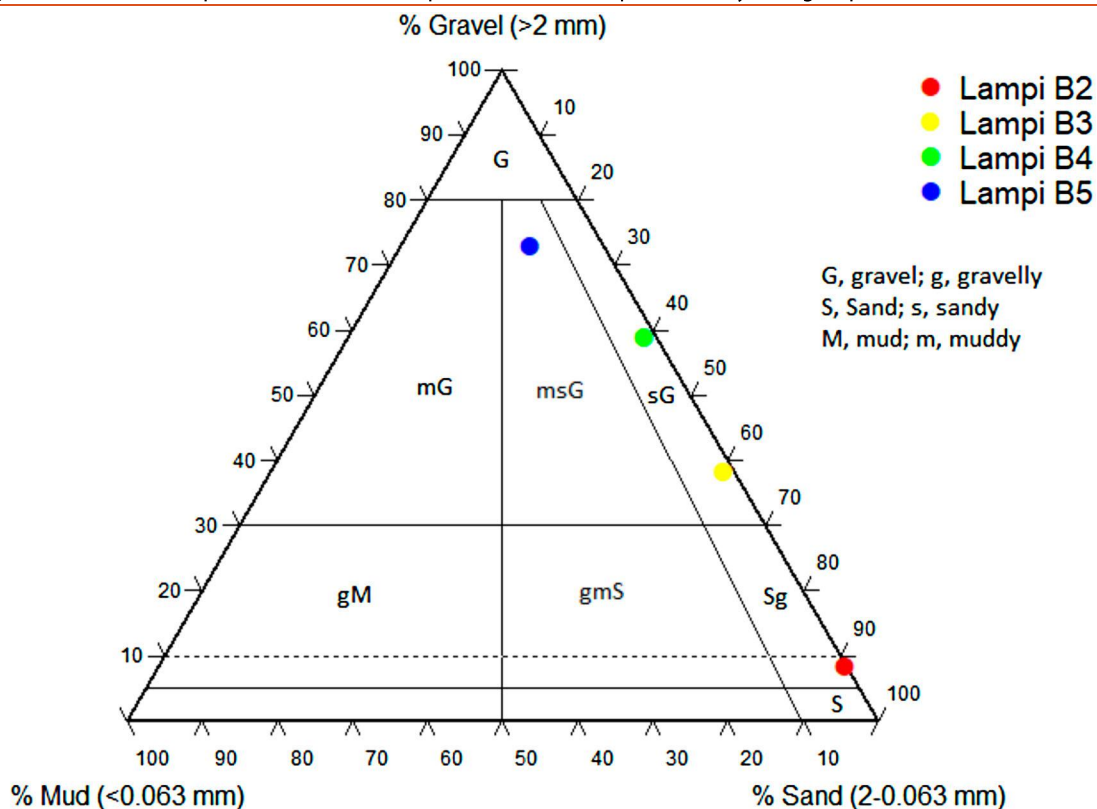
During the survey, both seafloor superficial samples and direct observations were carried out by using, respectively, a Van Veen grab and a Pollux III R.O.V (Remotely Operated underwater Vehicle) equipped with high-resolution video camera, for ground-truth

information. Figure 2 shows the locations and the coordinate points of the ground-truth data at Lampione. Unfortunately, due to adverse weather conditions coming, only a few samples were taken, mostly close to the islet, and this points to the need for future investigations for collecting a larger dataset. Samples were photographed on deck and their macroscopic lithological features described. Then, several sub-samples were taken from the homogenized sample, and grain-size analyses were carried out in laboratory. The sediments were washed with hydrogen peroxide solution (30% v/v) and distilled water; the gravel/sand fraction (4-0.063 mm) was analyzed using dry sieving. Grain size fractions were individuated according to the Udden-Wentworth scale (after Pettijohn, Potter, & Siever, 1987) and classified according to Folk (1980) (Table 1).

3.3. RSOBIA

In the study of marine environmental science with sonar technologies (e.g. Ierodiaconou et al., 2018; Lacharité, Brown, & Gazzola, 2017; Montereale Gavazzi et al., 2016; Stephens & Diesing, 2014),

Table 1. Weight percentage of the different granulometric fractions obtained through sample sieving and sediment classification according to Folk (1980). Sample LAMPI B6 is not reported since it is represented by a single specimen of rhodolith.



Name	Gravel (>2mm)	Sand (2-0.063mm)	Mud (<0,063mm)	Classification
Lampi B2	8.54	91.55	0.17	Gravelly sand
Lampi B3	36.47	57.38	1.38	Sandy gravel
Lampi B4	58.68	39.15	1.75	Sandy gravel
Lampi B5	72.88	17.04	9.8	Muddy sandy gravel

RSOBIA allows analyzing acoustic backscatter mosaic and bathymetric data characteristics (i.e. depth, roughness and slope) and, through the integration with other data such as ground-truth information, provides semi-automated acoustic seabed classification of multibeam images. RSOBIA is a new toolbox for ArcMap 10.4 that segments the data layers into a set of polygons with specific attributes (Innangi et al., 2018; Le Bas, 2016). The adopted segmentation process has been taken from RSGIS library of analysis and classification routines (Bunting, Clewley, Lucas, & Gillingham, 2014), modified to be suitable for the ESRI ArcGIS software under Windows operating system. In RSOBIA, The *Layering* function is a preparation step for segmentation. This function can combine many single layered files as required and creates a multi-layered raster (e.g. backscatter and depth). In the segmentation sub-menu there are three main optional parameters: the number of clusters, the minimum object size (i.e. the resolution) and the layer weights (see Innangi et al., 2018 for details). In this study, a multi-layered raster image was created, with backscatter, depth, roughness and slope layers respectively. The backscatter layers have been assumed as having three times the weight of the others (as in Innangi et al., 2018). Such segmentation is intended, in fact, to include DTM-derived variables (such as slope and roughness) although enhancing the role of backscatter signal by increasing its importance in the segmentation. Furthermore, for segmentation parameters of the layered image, were adopted 6 as the number of clusters, as it

was shown to be the optimal number of clusters after several trials, and 10000 as object size, in relation to the map scale.

4. Results and discussion

4.1. Bathymetric and backscatter data

The high-resolution DTM (1 m × cell) of Lampione (Figure 3(a)) shows a rugged seafloor all around the islet within the first 10–50 m depth, due to extensive rocky outcrops, localized talus deposits and boulders and pebbles (Figure 3(b)). The eastern and western submarine flanks of the islet are steep (in the order of 22–23°) while the slope is much gentler (around 5°) on the SE flank, down to about 45 m depth. Below 50 m depth, the seabed is almost flat (on average 0.40°, with a minimum value of 0.10° in the N-NW sector and maximum value of 0.60° in the S sector) and regular. The contours follow the general WNW-ESE orientation of the ‘Lampione-Lampedusa high’ (see section 2) and the seabed becomes gradually steeper at both sides of this structural high, below a depth around 65 m. The 1 m-resolution acoustic backscatter mosaic (Figure 3(c)) showed a lower variability in the acoustic facies with respect to that observed offshore the neighboring Lampedusa Island (Innangi et al., 2018; Tonielli et al., 2016). High backscatter values correspond to the rocky substrate of the islet submerged flanks (Figure 3(d)), while medium backscatter values (−45/−50 dB) prevails on the flatter surrounding area. Lower values (−53/

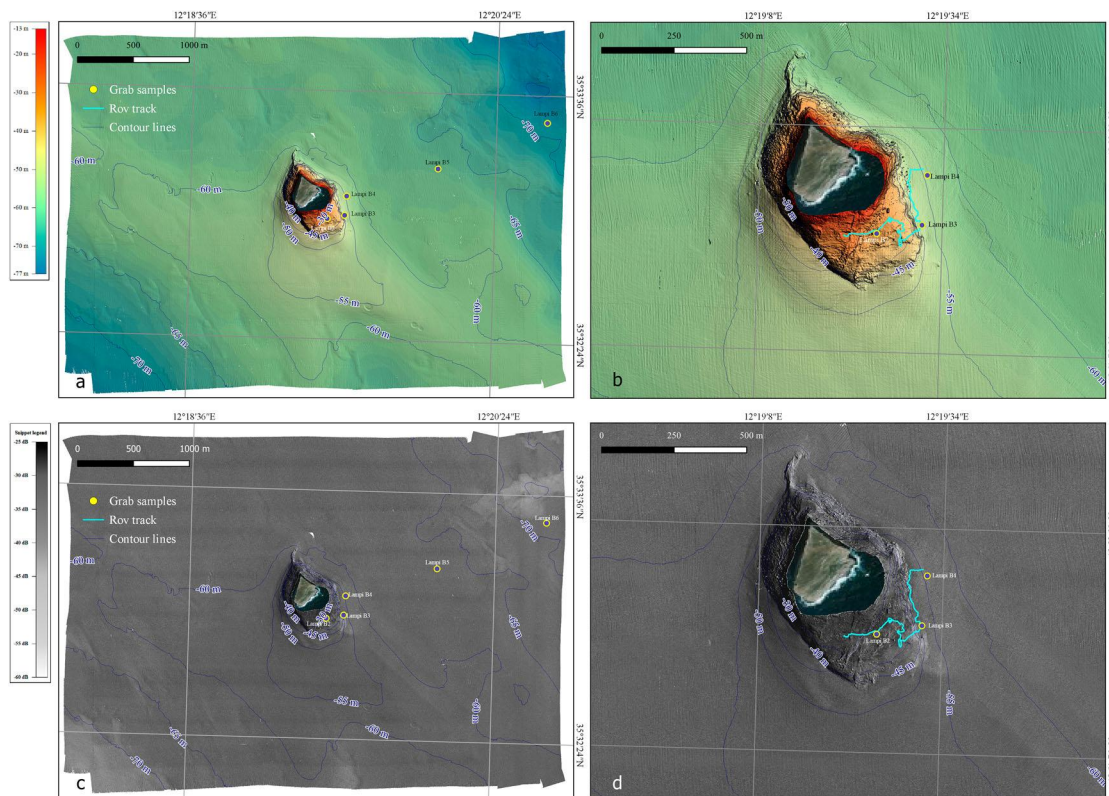


Figure 3. Bathymetry (in a and b) and Backscatter (in c and d) results of geophysical data acquired around Lampione Islet.

−56 dB) are recorded only below a depth of −70 m, at the NE and SW edges of the map, and locally in patches between −60 and −65 m. These patches correspond to depressions on bathymetry of about 0.40/0.50 m deep, more or less parallel to contours and stand on a seabed sloping about 0.30–0.50°. The backscatter facies, calibrated with the (limited) available ground-truth information derived from sea-bottom samples and video images, have been used in the RSOBIA segmentation.

4.2. Ground-truth data

A ROV transect (Figure 2 for location) was acquired to the S-SE of Lampione, in a range depth of about −23 to −55 m. Figure 4 shows some selected frames. The starting point is from a rocky substrate colonized by photophilic algae and scattered tuft of *P. oceanica* (Figure 4(a) at

about 23 m depth); sub-rounded boulders from the islet dismantling, interspersed with maërl and rhodoliths are present on the seabed (Figure 4(b,c) at about 25 m depth). Down to about 30 m depth, the *P. oceanica* disappears and mainly boulders, cobbles and pebbles colonized by photophilic organisms (i.e. sponges, bryozoa, algae and so on) and other calcareous-coral algae are observed (Figures from 4(d) to 4(f), from about 30 to almost 50 m depth). Note that the lithic clasts decrease with increasing depth, while the presence of maërl and rhodoliths increases (Figure 4(e)). In correspondence of the flat bottom all around (at 51–55 m depth), rhodolith and maërl beds completely cover the underlying substrate with the amount and size of the rhodoliths increasing with depth (Figure 4(g,h)).

Grab samples were collected after the ROV acquisition (Figure 2 for location). From the granulometric

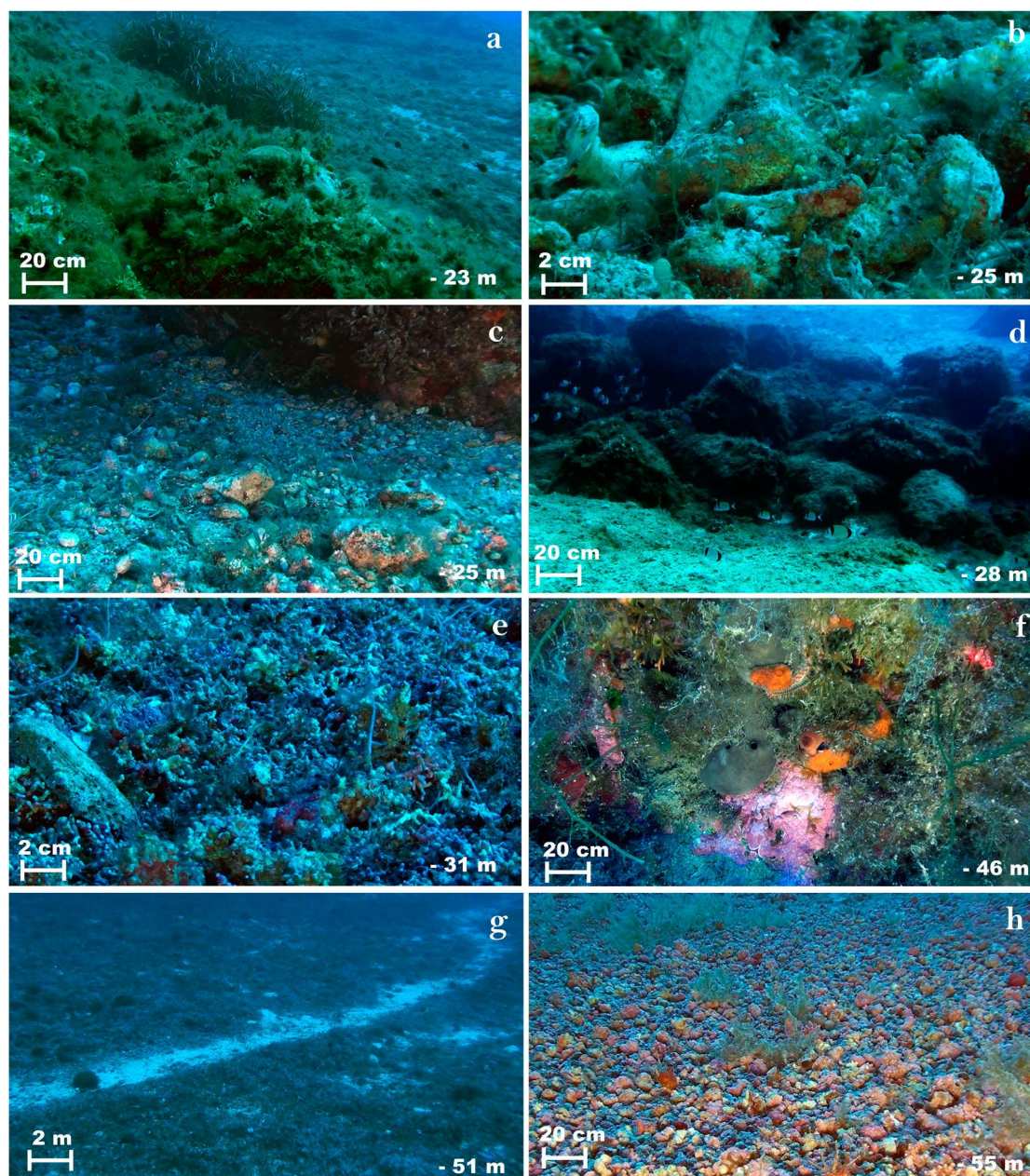


Figure 4. ROV video frames (see text for details).

classification (Table 1), it appears that the mud fraction increases with depth, while that of sand decreases (as expected). The increase in the gravel fraction from shallower (B2) to deeper (B5) samples is due to the presence on the seabed of rhodoliths that increase with depth both in quantity and in size

(see Figure SM.1). Finally, the deepest sample Lampi B6 (from 72 m depth, Figure 2 for location), consists of a single specimen of rhodolith (about 4 cm large, see Figure SM.1 g). The partial recovery of the latter sample, due to the failed closure of the grab, does not allow to verify the mud percentage at this depth,



Figure SM.1. Samples photographed on deck done during the survey “BioGeoLin 2017” (from ‘a’ to ‘d’, respectively) and some examples of rhodoliths founded in the samples processed (from ‘e’ to ‘g’, respectively).

that is expected to be higher than in shallower samples.

4.3. RSOBIA results

Before creating the layered image, the RSOBIA segmentation has been tested to the raster acoustic image of backscatter mosaic, where the image noise creates false classes in the segmentation (Figure 5 (a)). Then, the integration of the depth, roughness and slope layers allowed obtaining a better supported segmentation, based on multilayered raster image (Figure 5(b)). As previously observed at Linosa

(Innangi et al., 2018), in fact, the occurrence of well-developed rhodolith beds (and coralligenous habitat in general) tends to saturate the backscatter signal preventing the recognition of the below substrate, thus the use of RSOBIA is supportive to identify and map the classes dependent on slope and/or roughness changes. Moreover, this type of segmentation was further integrated with manual digitalization of acoustically lighter facies (Figure 5(c)), only partially identified by RSOBIA automatic procedure. The result of this last segmentation step was the base of the first seabed classification of Lampione, integrating on GIS application the morpho-bathymetric

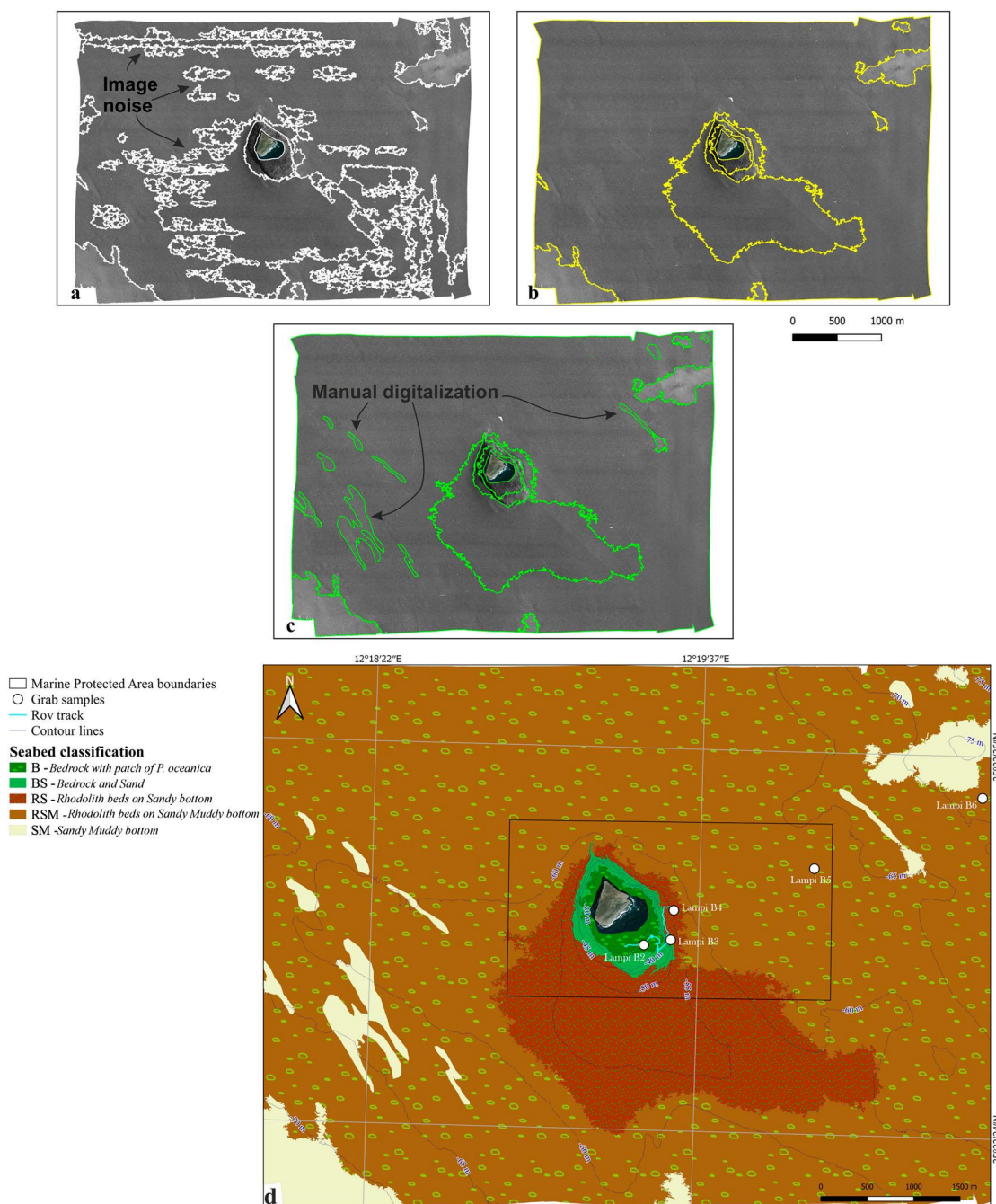


Figure 5. RSOBIA segmentation results; (a) segmentation on acoustic raster image; (b) segmentation on multi-layered raster image with backscatter layer assumed three times the weight of the others (i.e. depth, roughness and slope); (c) integration with the manual digitalization of acoustically lighter facies, only partially identified by RSOBIA automatic procedure; (d) Seabed classification map of Lampione Islet.

data with the available ground-truth information (see section 4.4).

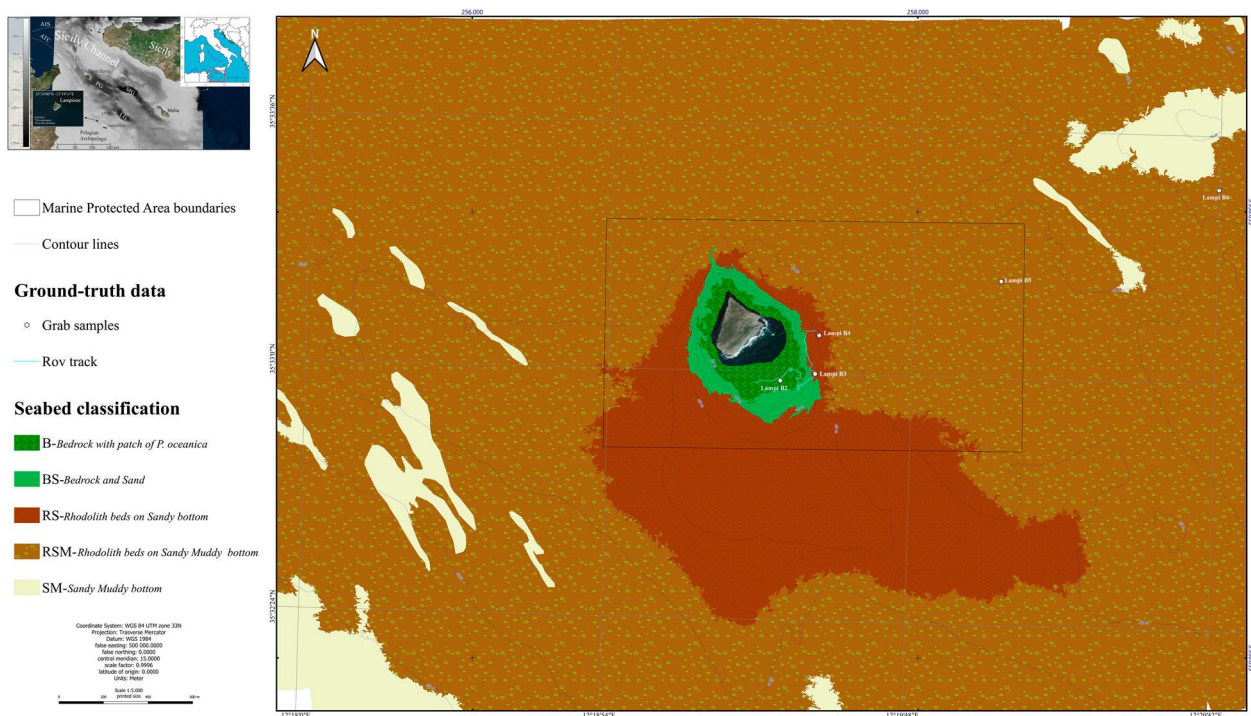
4.4. Seabed map

The first seabed map of Lampione Islet was originally drawn at a scale of 1: 5.000 (Figure 5(d) and Main Map). The seabed bathy-morphological characteristics and backscatter facies appear strongly dependent on the benthic habitat: both ROV investigations and grab samples confirm, in fact, the occurrence of a prevalent and widespread bioclastic sedimentary cover and a very well developed coralligenous habitat, with rhodoliths and maërl beds, similarly to what observed in the other Pelagie islands (Di Martino et al., 2017; Innangi et al., 2018; Innangi & Tonielli, 2017; Tonielli et al., 2016). Five main categories have been identified in the seabed classification and interpreted as follows:

- *B – Bedrock with patch of P. oceanica*: Rocky (carbonatic) substrate and boulders, commonly colonized by photophilic algae and locally by tuft of *P. oceanica* (see Figure 4(a)). Backscatter range is of $-25/-27$ dB (high reflectivity), with high roughness and slope. The class extends from the coast to a depth of about 30 m.
- *BS- Bedrock and Sand*: rocky substrate and detritic sediment (see sample Lampi B2, in Table 1 and in Figure SM.1a) without any evidence of *P. oceanica* and with an increase of rhodoliths and maërl down slope (see Figure 4). The gravelly sand is formed both by detritic and bioclastic elements. This class

was characterized by high backscatter variability (from -25 to -45 dB), as for roughness and slope. The class is included within a depth range of 30–45 m.

- *RS- Rhodolith beds on Sandy bottom*: Rhodolith and maërl beds (Figure 4(g,h)) on a sandy substrate (see samples Lampi B3 and B4 in Table 1 and Figure SM.1b and c). This class was characterized by a backscatter range of $-30/-40$ dB, low roughness and low slope. The class is included within a depth range of 45 to about 60 m.
- *RSM- Rhodolith beds on Sandy Muddy bottom*: Rhodolith and maërl beds on a sandy muddy substrate (see samples Lampi B5 in Table 1 and in Figure SM.1d and f and Lampi B6 in Figure SM.1 g). The average backscatter value of this class is about $-45/-50$ dB, while the roughness and slope are very low. The depth is variable, covering most of the remaining surveyed area, between -65 to -70 m.
- *SM- Sandy Muddy bottom*: Patches of sediment without rhodolith beds are mapped at depth below $-60/-75$ m mainly on the base of backscatter; no samples are available for this class. However, lighter backscatter tones indicate high acoustic absorption ($-55/-60$ dB), presumably due to the absence of rhodoliths on the bottom and the very fine grain-size of sediment (likely sandy/muddy). This class is distributed on steeper seabed below 70 m depth and in correspondence of elongated patches parallel to the local slope, suggesting the interaction with bottom currents that forms erosional scours or other kind of erosional bed-forms. Future investigations are necessary to better define this class.



Main Map

4.5. Other information in legend

Other information included in the map are: the location of the grab samples, the track of the ROV inspection, the contour lines and the boundaries of the MPA ‘Pelagic Islands’ of Lampione.

5. Conclusions

The preliminary mapping carried out around Lampione islet indicate that the seabed characteristics, up to the know almost unknown, are here strongly dependent on the benthic habitat. In particular, it is confirmed the high production in terms of coralligenous habitat, previously proposed on the base predictive modeling (Martin et al., 2014). The morphological conformation of Lampione, lying on a flat and shallow seafloor of the continental shelf under highly hydro-dynamical conditions, likely favors the development of rhodolith/maërl beds that completely cover the substrate. In addition, the presence of *P. oceanica* in patch was detected on the islet submerged flanks at least down to a depth of about 28 m. Actually, the reason for such a highly productive environment in marine area probably relies in the presence of favorable bathymetric setting, hydrodynamic and climatic regimes (Pinardi et al., 2015), besides a still low human impact in this area, especially for Lampione and Linosa (Innangi et al., 2018). Further investigations are needed to better define the fine-scale distribution of these sensitive habitat, crucial for their management and conservation (Martin et al., 2014). The use of RSOBIA (integrated by geomorphological, sedimentological and habitat observations) for Lampione, as well as for Lampedusa and Linosa (Innangi et al., 2018), allows the identification of discrete areas of the seabed having different bio-physical characteristics, such as bathymetry, occurrence of hard/soft substrate, sediment types and biological structures (Lacharité et al., 2017). This work thus emphasizes the use, in seabed mapping, of a semi-automated classification approach, with time-saving and simplified procedures that could guarantee the objectivity and repeatability of the application over time.

Software

Bathymetric data were processed with Teledyne PDS 4.1, as well as the final DTM. The snippet data were processed with FMGeocoder Toolbox (FMGT) in QPS Fledermaus 7.6 version. The segmentation was made with RSOBIA toolbar integrated into ESRI’s ArcMap GIS. The [Main Map](#) was produced using QGIS Madeira 3.4.2. Other cartographic images were made with Global Mapper software.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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