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Seafloor Map of the Alghero Bay (Sardinia, Italy)

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ABSTRACT

The Alghero Bay is a coastal area of high economic value because of the presence of one of the most popular beaches of Sardinia (San Giovanni, Maria Pia, Le Bombarde, Lazzaretto). The organisms living in the meadow of *Posidonia oceanica*, which densely cover the offshore areas of the bay, represent the most important source of sediments to these beaches. For this reason, a detailed mapping of the local seabed features and distribution of *P. oceanica* constitutes an important tool for the coastal managing of the area. The integrated use of several methodologies, such as Side Scan Sonar, Remote Operating Vehicle, Drone and direct sediment sampling has allowed us to realize a very detailed seafloor map of the Alghero Bay.

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Coastal management; *Posidonia oceanica*; beaches; seafloor bedforms; incised valley

1. Introduction

Seagrass meadows are some of the most productive and diverse coastal marine ecosystems on the planet. They provide nursery grounds and food for fish and invertebrates, carbon sequestration, and nutrient fixation (Duarte et al., 2018). The ongoing global warming and anthropogenic causes are responsible for a worldwide regression of these meadows (Duarte et al., 2018; González-Correa et al., 2007; Nicastro et al., 2013) causing sensible modification on shallow-water ecosystems of tropical range areas.

Posidonia oceanica (L.) Delile is the most important endemic seagrass species of the Mediterranean Sea and can form meadows or beds extending from the surface to 40–45 m depth (Telesca et al., 2015). For its importance, *P. oceanica* habitat has been included in the EC Directive 92/43/EEC (http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm). *P. oceanica* plays an important role in protecting (i.e. reducing the wave energy) and nourishing (i.e. supplying bioclastic material) the beach systems (De Luca et al., 2018; De Muro et al., 2008; Manca et al., 2013; Pergent, et al., 1995; Postacchini et al., 2019; Vacchi et al., 2016), but it is suffering the seagrasses worldwide regression. A detailed and continuous mapping of the seagrass distribution in the temperate regions, such as those of the Mediterranean Sea, it is, therefore, necessary to monitor this habitat and ensure its conservation (De Muro & De Falco, 2015; Tecchiato et al., 2015). Nonetheless, issues such as seafloor bedforms, sediment distribution, environmental modification, and human impact have to be considered as well to evaluate future coastal management strategies (Buosi et al., 2017; De Muro et al., 2016; De Jonge et al., 2015; James, 2000), in particular in areas where human impact is high.

In this paper, we combine Side Scan Sonar (SSS), submarine surveys and sampling, aerial photo and satellite image analyses to realize the Seafloor Map of the Alghero Bay (Sardinia, Italy).

In light of this, the specific objectives of this study are: (1) the *Posidonia oceanica* meadow, (2) the sandy seafloor bedforms. Mapping these features will allow us to describe the submarine dynamics and the effect of anthropic activities on the state of health of the *P. oceanica* meadow.

2. Area of study

Sardinia is the second biggest island of the Mediterranean Sea (Figure 1(A)) and one of the most important tourist destinations of Italy contributing significantly to the tourism industry and, therefore, to the Italian Gross National Product (GNP). The Alghero Bay (40°34′ N–8°13′ E) is located in NW Sardinia (Figure 1(B)) and extends from Capo Galera to Alghero Harbour, it has 14 km of coastline and a sea extension of 1600 ha (Figure 1(C)). To the northwest, it is delimited by the Marine Protect Area of Capo Caccia-Isola Piana (AMP) starting just west of Capo Galera promontory (Figure 1(C)) (De Luca et al., 2018).

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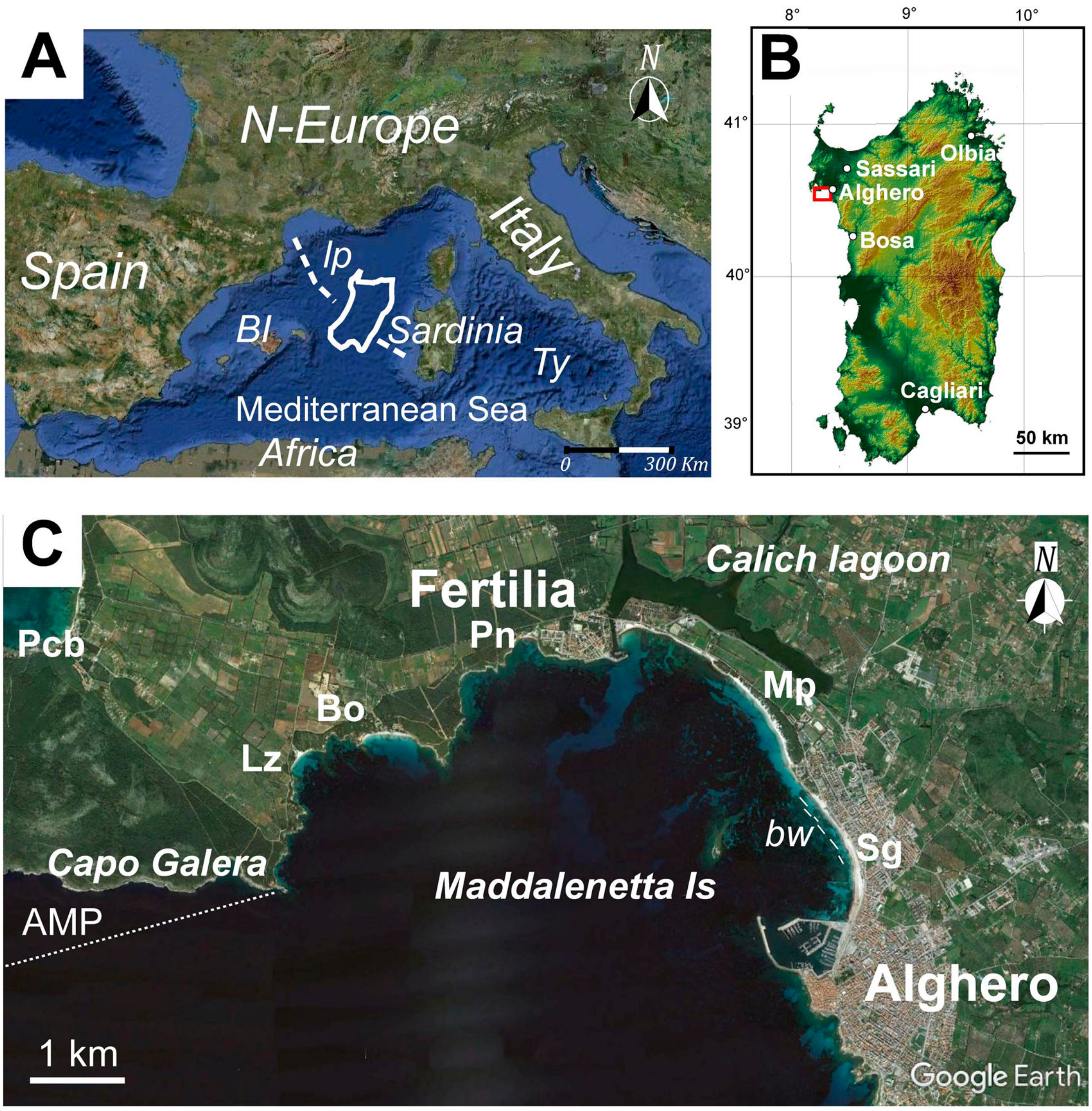

Figure 1. The study area (A) Satellite view of the Mediterranean region where Sardinia occupies a central position. Dashed line indicates the Sardinia anticlockwise rotation occurred in the Neogene time responsible for the opening of the Balearic and Liguro-Provençal back-arc basins; (B) Digital terrain model of Sardinia; in the map are reported the main cities. Alghero is on the north-west coast of the island. Red square refers to C. (C) Satellite image of the mapped Alghero Bay. The underwater canal, starting at the outflow tidal channel of the Calich Lagoon, is partially visible also from satellite image (from Google Earth, acquisition 2017). Bl = Balearic Islands; Ip = Liguro-Provençal Basin; Ty = Tyrrhenian Sea; Pcb = Porto Conte Bay; Lz = Lazzaretto beach; Bo = Bombarde beach; Pn = Punta Negra beach; Mp = Maria Pia beach; Sg = San Giovanni beach; *bw* = breakwaters barrier; AMP = Marine Protected area of Capo Caccia-Isola Piana; Maddalenetta Is = Maddalenetta Island.

Because of the numerous white beaches present along the bay and close to the city, Alghero is one of the most important touristic destination of Sardinia (Rodella et al., 2020). Beaches are fed by small and ephemeral rivers flowing into the Calich Lagoon (Figure 1(C)) and mainly active during autumn and winter when rainfalls are more intense. A consistent part of the material nourishing the beaches is eroded from the surrounding cliffs (Figure 1(C)), in particular from late Quaternary deposits (Pascucci et al., 2014). Most of the rivers, even small, are nowadays dammed for water supply. This had as result a decrease of sediments load carried into the Alghero Bay (Ginesu et al., 2016). Main consequence of this is that beaches are mostly nourished by bioclats derived from organisms living in the wide *Posidonia oceanica* seagrass meadow present offshore the coast (Manca et al., 2013). The bay is also characterized by several anthropic features such as harbours (Alghero to the south and Fertilia to the north) and breakwaters (*bw*, southernmost part of the bay) (Figure 1(C)) that have strongly modified the natural longshore sediment transport (Manca et al., 2013; Postacchini et al., 2019). Mapping of the seafloor plays, therefore, a key role in the management and conservation of this beach environment.

2.1. Morphological setting

The present morphological setting of the Alghero Bay formed since ~8 ka BP when the post Last Glacial

Maximum (LGM, 20 ka BP) sea-level rise decreased (Pascucci et al., 2014; Palombo et al., 2017). The present-day Alghero beach-lagoon system developed at about 3 ka BP (Andreucci et al., 2017a). The present climate started to establish between 6 and 5 ka BP and become stable about 3 ka BP, after which just small amplitude climate fluctuations (0.5–1°C) occurred (Pascucci et al., 2018, 2019).

The Alghero Bay forms an arch open to the SW and may be subdivided into two sectors separated by the harbour and the urban area of Fertilia (Figure 1(C)). The southwestern sector stretches from Capo Galera to the Fertilia Harbour. It is characterized by a rocky shore delimiting the small pocket beaches of Lazzaretto (Lz), Bombarde (Bo) and Punta Negra (Pn) (Figure 1 (C)). The southeastern sector is characterized by the 4.5 km long Alghero beach-lagoon system. The beach is NNW-SSE oriented and comprises the partially urbanized beach of Maria Pia (Mp) and the urban beach of Lido di San Giovanni (Sg) (Figure 1(C)). This last is protected from erosion by~700 m of semi-submerged breakwaters barriers (bw) built in 1983 (Manca et al., 2013) (Figure 1(C)). The beach is composed of unimodal, well-sorted sand varying in size from 339 to 190 µm (mean value) from north to south. It shows a slight erosional trend especially caused by large winter storms (Manca et al., 2013). A small rocky island (Maddalenetta Island), made of Oligo-Miocene ignimbrites, is located in front of Lido San Giovanni beach (Figure 1(C)).

2.2. Meteoclimatic setting

Northwest Sardinia is characterized by a warm temperate, marine climate with an average temperature ranging from 7°C in winter to about 25°C in summer. It is featured by a wet season (October to April), accounting for 80% of the yearly precipitation with frequent heavy rainstorm events and a dry season (May to September) (Delitala et al., 2000). The dominant effective wind is from the northwest (Mistral wind) and is responsible for NW-SE longshore drift along the northwest coast of Sardinia (Donda et al., 2008). The sea is microtidal with storm waves up to about 7 m high and wind running more than 100 km/h (ARPA-Sardegna, 2019; Manca et al., 2013). The most frequent waves (75%) generally come from the 295°–330° N direction and frequently are characterized by a significant height of 2 m (APAT, 2006; https://www.emc.ncep.noaa.gov/). Smaller waves from southern sectors, 190°–225° N account for 5% of the total. The maximum wave height recorded for this sector was 9 m (Manca et al., 2013; Vicinanza et al., 2013).

The mean wave period is comprised between 2 and 13 s, with the longest periods for the largest waves from the NW. The most common waves (2 m height) have a mean period of between 3.5 and 6.5 s (APAT, 2006; https://www.emc.ncep.noaa.gov/). Waves from NW storms are refracted by Capo Caccia promontory sheltering the Alghero Bay beaches that are directly exposed to waves coming from the W-SW sector (190°–270° N) (Figure 1(B,C)). Southwestern storms are also responsible for the winter beach erosion.

2.3. Geological setting

Sardinia represents a segment of the south-European plate that separated from it as the result of an anticlockwise rotation consequence of an important back-arc extension, which took place during the Oligocene–early Miocene (Doglioni et al., 1998) (Figure 1 (A)). Associated with the lithosphere stretching, several NW–SE oriented basins formed (Carmignani et al., 2015), and Miocene Pliocene shallow-marine to continental deposits developed (Andreucci et al., 2017b; Casula et al., 2001; Telesca et al., in press).

Sardinia is considered tectonically stable since the late Pliocene (Gueguen et al., 1998; Patacca et al., 1990), but minor vertical movements at metre scale in local areas have been recognized (Casini et al., 2020; Cocco et al., 2019).

Mesozoic carbonate and Late Quaternary marine to alluvial deposits crop out along the Alghero Bay (Carmignani et al., 2015). These deposits formed as a consequence of the last 300 ka sea-level fluctuations and provide most of the clastic material feeding the numerous pocket beaches present along the bay (Pascucci et al., 2014). Marine deposits mainly consist of conglomerates, shallow-marine fossiliferous carbonates, and sandstones referred to Marine Interglacial Stages (MIS) 7 and 5 (Sechi et al., in press). Non-marine deposits consist of coastal aeolian sandstones interlayered by fine-grained sandstones and siltstones (colluvia and paleosols) (Andreucci et al., 2014; Zucca et al., 2014a, 2014b) and alluvial conglomerates, which are usually attributed to glacial stages (Andreucci et al., 2010; Palombo et al., 2017; Pascucci et al., 2014, 2019).

3. Methods

The Alghero Bay sea floor map was made integrating Side Scan Sonar (SSS) data with submarine surveys, aerial photograph and satellite images analyses. 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 survey swath of 150 m and an overlapping of at least 20%. The used aerial photos are orthophotos 2008 (Sardinia region, RAS); satellite are Google Earth images (2009–2017) and BaseMap Esri images 2018 (Digital Globe) with a resolution of 0.5 m and accuracy of 10.2. Additional aerial photos have been acquired during 2019 with a drone (Unmanned Aerial Vehicle-UAV) DJI Mavic

Pro equipped with a 12 Mpixels camera mounted on three-axis gimbal support to ensure the maximum stability and a GPS/GLONASS positioning system (0.1 m accuracy). 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 degrees and with two 50-watt halogen spotlights. Sediment sampling was done with direct scuba diving using an 8 × 40 cm plastic core. Sediment grain-size was performed on the sandy fraction of the samples, after wet sieving and drying in the oven at 60°C for 24 h. Data on the sand grain size was obtaining using a stack of sieves with ½ phi intervals. Statistical geometric analysis was performed using the Gradistat software (Blott & Pye, 2001) and Folk and Ward Method (Folk & Ward, 1957).

Data interpretation was made following the scheme: first SSS photomosaic has been interpreted and a map based on acoustic facies performed; the map of the shallow water and underwater canal part has been realized using photomosaics (ortophoto and Google Earth). High-resolution photos acquired by UAV of particular areas (i.e. shoreface and shallow water intramatte channels) have integrated these data. Finally, truth points were acquired during 2019 both using ROV and direct scuba dives performed in selected sites. Each data was a layer and GIS tools were used in the production of different maps.

The final map was edited at a scale of 1:12,000 and made interpreting a 0.250 m pixel resolution.

4. Results

The Alghero Bay mapped area has been ideally subdivided into three environmental units (Units 1–3), representing areas with similar biocenotic, sedimentological and morphological conditions and human activities (Figure 2). The adopted subdivision refers to Pérès and Picard (1964) and to the adjacent map of the Marine Protected Area Capo Caccia-Isola Piana (De Luca et al., 2018).

4.1. Environmental unit 1: the *Posidonia oceanica* seagrass meadow

Unit 1 occupies 1509 ha accounting for more of 66% of the total mapped area. It could be further subdivided into a western and eastern part separated by an underwater channel (Unit 2). In the western part, the seafloor between the shoreline and the lower limit of seagrass meadow is made of Mesozoic carbonates, being the underwater continuation of the carbonate rocky cliff characterizing this part of the bay. Landward, these rocky outcrops delimit three SW facing pocket beaches (Lz, Bo, Pn; Figure 1(C)) mostly made of medium (387.3–254.0 μm; Figure 3), well sorted, symmetrical to fine skewed, meso and leptokurtic sand, composed of up to 45% of siliciclastic and 55% carbonate (bioclastic) grains. The *Posidonia oceanica* meadow occupies 721.6 ha and is found at depth comprises between −5 and −35 m (Main Map). Intra-matte channels are rare and mostly concentrated in the SW side of the area (close to Capo Galera) where they join to form elongated features about 1 km long (Figure 3; Main

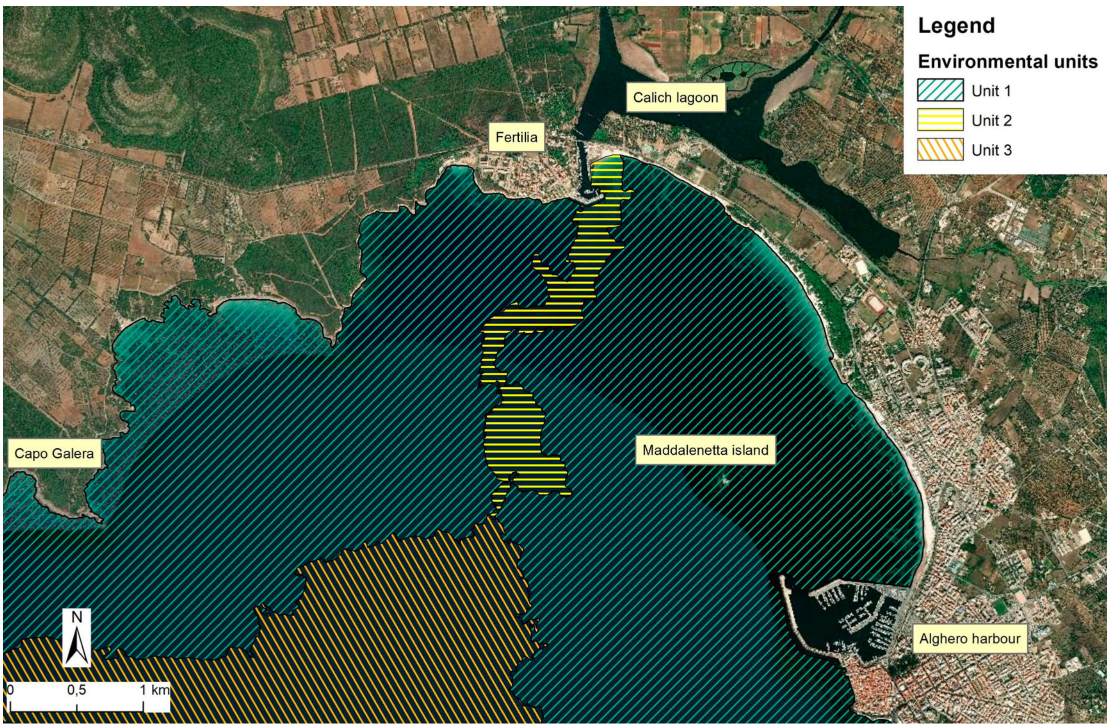

Figure 2. Environmental units: Unit 1: The *Posidonia oceanica* seagrass meadow; Unit 2: 'The canal'; The Unit 3: the outer shelf.

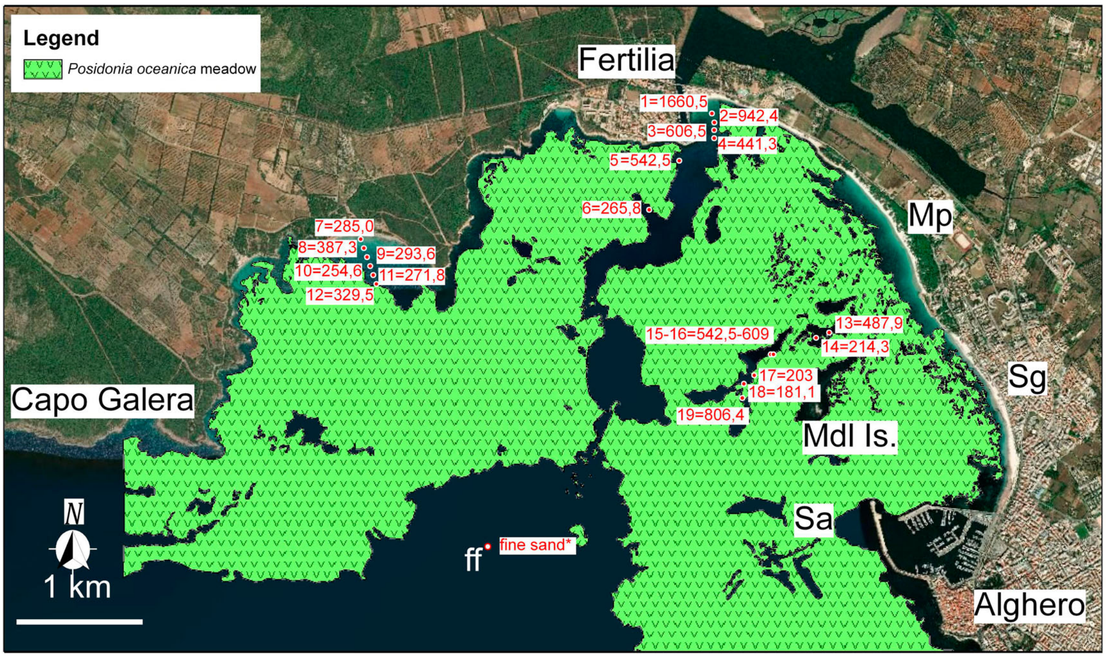

Figure 3. *Posidonia oceanica* meadow distribution in the Alghero Bay. Note how intra-matte channels are mostly concentrated close to the Maddalenetta Island (Mdl Is.), Maria Pia (Mp) and San Giovanni (Sg) urban beaches. With read labels are indicated the collected samples (1–19) and the relative mean value grain size is expressed in µm. Sa = Cruise ship anchorage; fine sand* has been sampled close to the Maricultura di Alghero fish-farm = ff by Forchino et al. (2011).

Map). In the eastern part, the seagrass (786 ha) bounds the medium to fine sandy shore of the Alghero beach-lagoon system. This part is interested by a high concentration of intra-matte channels (over 300). The highest density is concentrated at shallow depth (−10 m) and between the La Maddalenetta Island and the sandy shoreline, whereas biggest channels occur N and NW of the island (Figure 3, Main Map). Their floor is made of sand and mostly characterized by variously oriented ripples; some dunes may be found as well.

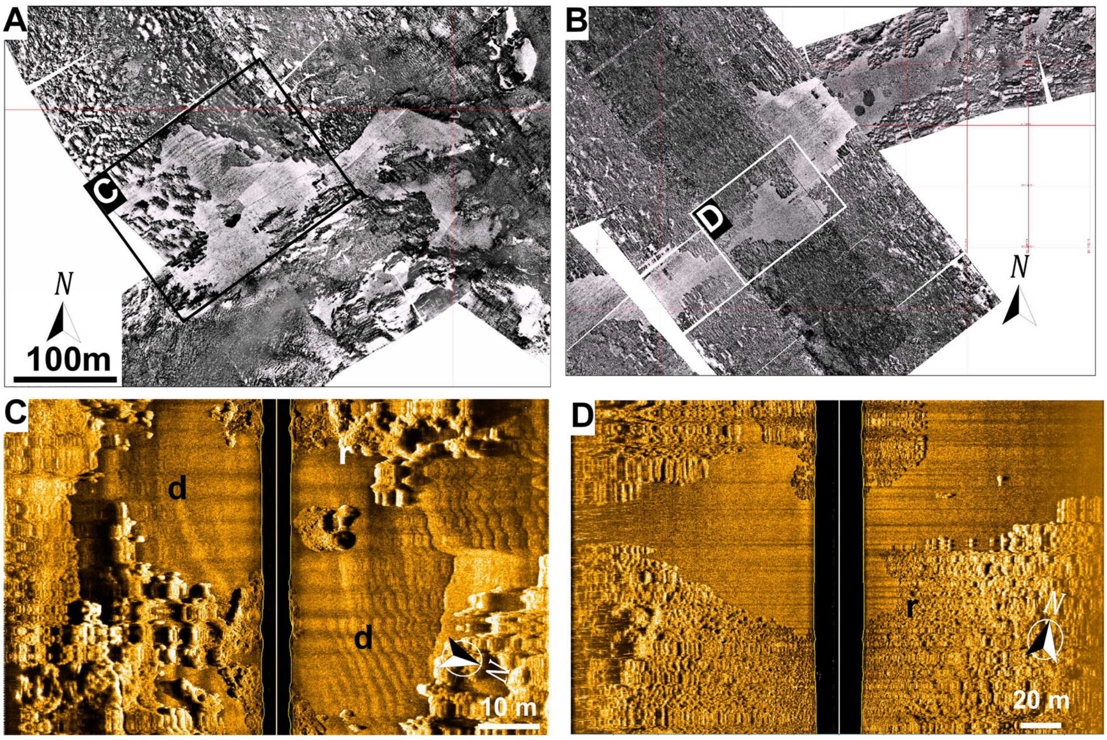

Figure 4. Side Scan Sonar images of the intra-matte channels. (A) SSS mosaic frame of the X-shaped intra-matte channel; (B) SSS mosaic frame of the reverse Y-shaped intra-matte channel. (C) High resolution SSS image of NW-SE oriented dunes (d) paving the northernmost part of the X-shaped intra-matte channel; ripples (r) occur in the most sheltered part; (D) High resolution SSS image of NNW-SSE oriented ripples (r) covering the floor of the Y-shaped intra-matte channel.

Two of these intra-matte channels have an X-shape (Figure 4(A)) and reverse Y-shape (Figure 4(B)) and extend for about 0.5 and 1 km respectively in NE-SW direction (Figures 3 and 4). Their sediments have been sampled and grain size is considered representative of all intra-matte channels of the Alghero Bay. They are made of coarse (806 μm) to fine (203 μm) (Figure 3), moderately to poorly sorted, meso to leptokurtic, coarse skewed sand, composed of 30–35% siliciclastic (quartz up to 25%) and 70–65% bioclastic (bivalves up to 15%) grains. Coarse sand mostly occurs in the landward side of the intra-matte channels whereas, finer characterizes the distal (Figure 3). In the X-shaped channel, dunes occur in the lateral part (Figure 4(C)), whereas ripples in the centre (Figure 4 (A)). The Y-shaped channel is almost entirely paved by ripples (Figure 4(D)). Dunes and ripples are mainly NW-SE oriented (Figure 4(C, D)).

4.2. Environmental unit 2: 'the canal'

Unit 2 is characterized by the presence of an underwater north–south-oriented channel (The canal), 2.5 km long and 300 m wide, occupying an area of 87.7 ha (Figures 1(C)–3, Main Map). The canal is visible from satellite images and develops from Fertilia Harbour up to −25 m depth. Side Scan Sonar have imaged the canal in all its length confirming it represents the seaward continuation of the tidal outflow channel of the Calich Lagoon (Figures 1(C) and 5). It is meandering shaped and characterized by narrowing and widening areas in the central (15–20 m depth) and terminal (>25 m depth) parts. This last forms a wide sub-circular delta-like feature (Figures 2 and 5(A), Main Map). The total canal gradient does not exceed 1.5%, and in the highest landward part, it is lower than the seagrass meadow of 7 m. The canal sediments have been sampled from −10 to −13 m depth (Figure 3). They are made of very coarse (mean value = mv 1660.5 μm) to medium sand (mv 441.3 μm) in the proximal part close to the Fertilia Harbour, whereas in the more distal they range in size between 542.5 and 265.8 μm (mv). All sampled sands are moderately sorted, with variable kurtosis and generally coarse skewed. Siliciclastic components are up to 60% whereas bioclastic do not exceed 40%. Finer sand occurs along the sheltered side of the canal where ripples are the dominant sedimentary structure. Ripples are straight, with an average wavelength of 0.5 m, up to 0.3 m high and prevalently oriented NW-SE, although their orientation is mostly dependent from the canal morphology (Figure 5(B)). Where the canal enlarges and coarser sand dominates, dunes are the main structures (Figure 5(C)). At the border of the canal, dunes are continuous and straight, with an average wavelength of 6 m and up to 1 m high. In the centre, they appear isolated, sinuous having in places a parabolic shape (Figure 5(C)). Isolate dune (or mega dune) size structures occur in many part of the canal floor. Preferential orientation of the dunes is NE-SW; this indicates they formed as a consequence of an NW coming current.

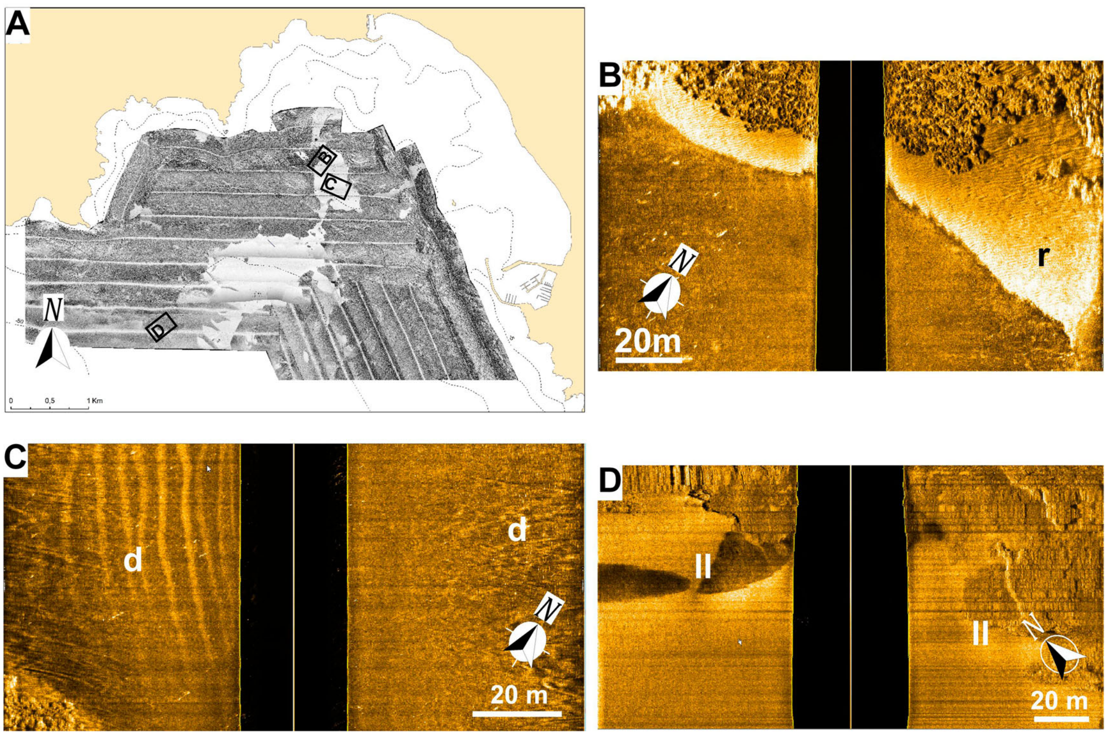

Figure 5. Side Scan Sonar images of the canal. (A) SSS mosaic of the Alghero Bay; (B) High resolution SSS image of ripples (**r**) occurring in the most sheltered part of the canal. (C) High resolution SSS image of dunes (**d**); they are the most recurring sedimentary structure of the canal; (D) High resolution SSS image of lower limit (**ll**) of the *Posidonia oceanica* seagrass meadow.

4.3. Environmental unit 3: the outer shelf

Unit 3 occupies the outer shelf below −30 m depth; that is, almost below the lower limit of the *Posidonia oceanica* meadow (Figures 2 and 5(D)). It has an area of 382 ha. Sediments have not been sampled and their character has been defined using Side Scan Sonar backscatter and data acquired by Forchino et al. (2011) around the fish-farm cages (Figure 3 and Main Map). According to Donda et al. (2008), the lower backscatter indicates the finer sediment. We have distinguished bioclastic gravel and sand (15%), mostly occurring immediately below the *P. oceanica* meadow lower limit, mixed bioclastic sand and fine sand (200–100 µm) (33.5%) representing the canal outflow (delta part of the canal), and mixed bioclastic fine sand and mud (<64 µm), occurring at depth greater than −40 m and representing the outershelf deposit (51.5% of the total area). No major sedimentary structures have been recognized in this unit, although some ripples occur close to the lower limit of the *P. oceanica* meadow.

4.4. Discussion

The mapping of the Alghero Bay has underlined two main aspects: (i) the *Posidonia oceanica* meadow and (ii) the underwater canal connecting the outflow tidal channel of the Calich Lagoon (Fertilia Harbour) with the outer shelf.

The meadow appears overall compact and in good shape. However, several intra-matte channels characterize the shallower part of the meadow. They are concentrated between 0 and −7 m depth, and the maximum is reached close to the La Maddalenetta Island and in front of the San Giovanni (Lido di Alghero) beach (Figure 3 and Main Map). This area is the most attended because sheltered, in front of a touristic beach and very close to the Alghero and Fertilia harbours. All these make easy to navigate or swim (or paddle) to it. Several boats in fact anchor protected by the small island and rocky shoal without any significant control. This intense human activity, concentrated in summer time, may have yielded an increase of fragmentation and retreat of the *Posidonia oceanica* meadow upper limit allowing the joint of intra-matte channels, such as X-shaped. 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). Wide intra-matte channels (0.5 km long and 50–100 m wide) are also present at depth between −10 and 20 m in front of the SW facing dock of the Alghero Harbour. These last are related to the anchoring of cruise ship (Figure 3). Dragging anchors and scraping anchor chains along the bottom, as these big boats swing back and forth, results in huge dislodgement of plant rhizomes or leaves and in the excavation of channels (Milazzo et al., 2003).

We do not have, instead, any prove that the reverse Y-shaped intra-matte channel present between −7 and −18 m west of the La Maddalenetta formed as a consequence of human activities. The easier explanation is that it represents the rip currents channel forming during major storms. This hypothesis is supported by the presence of dunes and ripples southwestward oriented in accordance with the outgoing storm current model proposed by Postacchini et al. (2019).

The underwater canal lies about 7 m below the seagrass meadow, has a low sinuosity, and tractive sedimentary structure is the most recurrent. The total absence of vegetation as well as its widening at depth of −15 to 20 m and the delta like feature at depth of −25 to 30 m characterizing its terminal part are surely the main features.

The diffuse presence of NE-SW oriented dunes indicate that along the canal is active an intense current able to mobilize coarse and medium-grained sand (Figure 5(D)). This sand motion, triggered by the dominant NW coming wind, is most probably continuous and not allows the growth of vegetation.

The widening of the canal and the delta-like feature are surely of interest for palaeogeographic reconstructions and could be associated with Holocene still stands.

The canal represents an incised valley formed during the dry-up of the post Eemian (125 ka) Calich Lagoon (Zucca et al., 2014b) and the consequent new river path formation occurred during the following glacial times. As a consequence of the post-LGM (about 20 ka BP; Clark et al., 2009) rapid deglaciation, sea-level rose and reached at about 11.8 ka BP (beginning of the Holocene) the depth of −55 m below the present sea level (bpsl) (Lambeck et al., 2004, 2011). For western Sardinia, Vacchi et al. (2016) estimated that: (1) at ∼10.8 ka BP sea level was at −45.5 ± 1.6 m bpsl; (2) at ∼9.7 ka BP RSL was at −29.5 ± 1.0 m bpsl; (3) at ∼9.4 ka BP RSL was at −27 ± 1.0 m bpsl; (4) at ∼7.0 ka RSL at −13.9 ± 1 m bpsl, and between ∼4.6 and 4.0 ka BP, RSL was at−6.8 ± 1.0 m bpsl. Pascucci et al. (2018) pointed that still stand of the Holocene sea-level rise occurred at: (1) about 8.2–8.5 ka BP when sea level was at between −25 to −30 m bpsl, and (2) about 7.2 ka BP when the sea level was at −15 bpsl.

We assume that the delta formed during an RSL still stands occurred between 9.0 and 8.2 ka BP (average RSL −25 m) after the meltwater pulse Mwp-1c, while the landward enlargement between 7.5 and 7.0 ka (average RSL −15 m) after the meltwater pulse Mwp-1d (Gorniz, 2013). These data are in agreement with an RSL rise of 10-15 mm/y^{-1} estimated for the Oristano Gulf (100 km southward; De Falco et al., 2015) and also with the palaeogeographic model proposed by Orrù et al. (2005) and revised by Palombo et al. (2017) for the close by Porto Conte Bay (Pcb, Figure 1). The no preservation of this old beach systems (beachrocks), common in other part of Sardinia Island (i.e. Bonifacio stratit, Oristano Gulf, Cagliari, De Falco et al., 2015; Vacchi et al., 2018) could be explained with the little sediment supplied by river system feeding the incised valley and/or by the lack of an early cementation of the beaches.

Fish-farming (ff, Figure 1(C)) has been realized in the delta area at −38 m depth (La Maricoltura Alghero s.r.l.' Latitude 40°33′43.9″N, Longitude 8°16′09.0″E) on fine sand floor characterized by current varying from 2.8-3.0 cms^{-1} at −13 m to 1.5–1.8 cms^{-1}, at −33 m oriented toward the NW (Forchino et al., 2011). The most common negative environmental impacts associated with aquaculture include waters eutrophication, water quality, alteration or destruction of natural habitats, introduction and transmission of aquatic animal diseases (FAO, 2006). SSS imaged below the fish-farm does not evidence any environmental modifications. Moreover, the relative high speed of the bottom current and its more or less continuous presence throughout all year is most probably responsible for the dispersion of the organic matter and mobility of the sedimentary structures present in the canal.

5. Conclusions

The mapping of marine habitat plays a key role in the management and conservation of natural systems and provides the spatial framework for ecosystem-based management (EBM) (Deiana et al., 2019). It has been estimated that only 5–10% of the seafloor is mapped at a comparable resolution to similar studies on land (Wright & Heyman, 2008). Furthermore, marine ecosystems are poorly described compared to their terrestrial counterparts (Deiana et al., 2019). On land, the proportion of unknown habitats has been estimated as 17% whilst for the marine realm, it has been estimated as 40% (EC, 2007).

In Sardinia, the coastal ecosystem is an area of complex interaction between geological, ecological and anthropogenic processes. The study of these processes is of basic importance for the implementation of ecosystem-based management of the sea and in assessing the consequences of human activities (Deiana et al., 2019; De Luca et al., 2018; De Muro et al., 2018; Manca et al., 2013).

The first seafloor map of the Alghero Bay indicates that *Posidonia oceanica* meadow covers an area of 1300 ha, the upper limit of the meadow is highly fragmented and discontinuous and intra-matte channels are very numerous. Various human practices related to the direct or indirect effects of tourism are responsible for fragmentation of the *P. oceanica* meadow.

The map has detailed the underwater canal representing the outflow continuation of the Calich Lagoon tidal channel. The canal formed during the LGM as an incised valley being progressively filled by backstepping processes that followed the post-LGM relative sea-level rise. This Holocene sea transgression was not continuous but at least characterized by two still stands occurred between 9.0- 8.2 ka and 7.5 −7.0 ka BP.

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) and SeaView 1.5.58 (Moga Software srl). Spatial analyses were performed and processed using ArcGIS Desktop version 10.7 (ESRI). Grain size analysis was performed using Gradistat Version 9.0 for Excel versions 2007–2013 and Microsoft 365 (.xlsm) and free available at http://www.kpal.co.uk/gradistat.html.

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