PHYSICAL HABITAT STRUCTURE IN MARINE ECOSYSTEMS: THE CASE STUDY OF REYNA BAY, CONSTANȚA

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Abstract. Reyna Bay, an artificial bay on the northern Romanian Black Sea coast near Constanța, underwent significant modifications between 2015 and 2016 to protect against erosion. Reinforced embankments and submerged spur dikes were installed to stabilize the shoreline, while newly added sand with a high shell fragment content can mitigate sediment loss. This study focuses on habitat mapping in Reyna Bay, covering an area of 400 m in width and extending up to a kilometre beyond the bay.

Habitat mapping is crucial for understanding the distribution of marine habitats, especially in areas where coastal interventions alter natural processes. This research aims to provide a detailed habitat map of the bay using a combination of modern remote sensing techniques, including acoustic classification methods for seabed sediments. By integrating bathymetric, sedimentological, and biological data, the study not only assesses current seabed conditions but also contributes to European marine biodiversity efforts through data-sharing initiatives, such as the European Marine Data Portals and the EUNIS classification system.

The primary objective of this study is to classify and map seabed habitats using advanced technologies such as multibeam and singlebeam echosounders, sidescan sonar, and sediment sampling. The collected data was validated through ground truthing and biological sampling, ensuring an accurate habitat classification. By studying the area both within and outside of the bay, this research reveals how recent coastal modifications have influenced sediment distribution and habitat structure.

Key words: physical habitat mapping, geophysical measurements, Romanian Black Sea Coast

1. INTRODUCTION

Reyna Bay is located in the northern part of Constanța City, Romania, part of the western coast of the Black Sea. Onshore, Reyna Beach is one of the famous beaches on the Romanian Black Sea coast.

Our study area is located nearshore, having a maximum depth of 10.3 m, bordered in the north and south by embankments. There are two submerged spur dykes in the area. The inner, older one, is located at 140 m from the shore, having a length of 150 m, while the outer one (newer, built in the same time as the north and south embankments) is at 400 m from the shore and has 280 m length. Both have a general direction of 160° (Fig. 1). The distance between the dykes and the north and south embankments are 280 m in the north and 120 m in the south. This creates a limit in which the internal bay is affected by currents and waves while exchanging waters with the outer area.

1.1. Geological setting

During its geological history, the Black Sea experienced significant fluctuations in sea level. About 18,000 to 20,000 years ago, during the Last Glacial Maximum, the sea level was estimated to be 80 to 100 meters lower than its present-day level (Panin, 1999; Strechie-Sliwinski, 2007; Lericolais *et al.*, 2009, 2011).

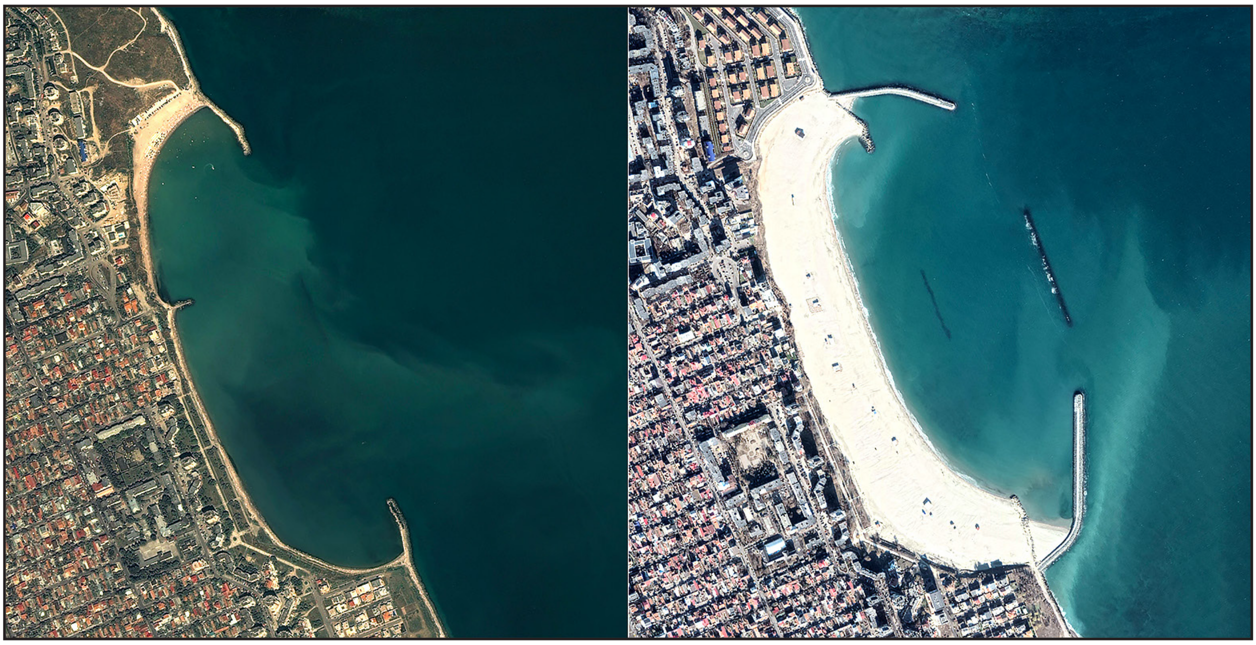

Fig. 1. Reyna study area before (left) and after (right) enlargement of the beach (Images: Google Earth – Maxar Technologies). The image to the right shows the new embankments together with the outer submerged spur dike. The inner spur dike was constructed previously. The former embankments, north and south of the bay were eliminated. The added sand widens the beach with approximately 120-130 m.

The precise mechanisms and timing of the subsequent sea-level rise are still subject of debate, with studies continuing to refine our understanding of the Black Sea's complex paleoenvironmental evolution.

The coastline of Constanța, including Reyna Bay, lies within the South Dobrogea tectonic block of the Moesian Platform, which has been relatively stable since the Mesozoic Era. The presence of several fault systems, particularly NW-SE, N-S and NE-SW trending (Visarion *et al.*, 1988; Dinu *et al.*, 2002, 2005; Oaie *et al.*, 2016; Diaconescu *et al.*, 2019; Stanciu, 2020), indicates past tectonic movements, with an essential role in the achievement of the current structural framework and geomorphological evolution of the region, shaping the coastline and influencing sediment deposition patterns.

The local lithology consists mainly of loess, covering Sarmatian limestone. Reyna Beach sand includes mainly coarse sand and shell debris, supplemented by fragments of limestone, set in place as a combined result of long-term erosion and sediment transport mechanisms, and of the Black Sea's hydrodynamic processes (Halcrow, 2012). Through beach feeding processes carried out in 2015-2016, sand with a high content of shell and shell debris was added, which resulted in a ca. 120-130 meters wider beach. This sand is sourced from an offshore location and is coarser than the original substrate.

The predominant direction of coastal sediment transport influenced by waves and marine currents is from north to south. However, there are places where reverse movements occur, due to geomorphological features of the shore, the orientation of the coastline in relation to the direction of waves and due to existing built structures, such as jetties. The Danube-transported fine sands barely reach this area, due to Sulina and Midia jetties, which disrupt the longshore sediment transport since their installation.

1.2. Hydrological considerations

The Black Sea, an inland sea with minimal tidal variation, lacks tidal currents (JICA, 2007). Currents responsible for alongshore and cross-shore sand transport are generated by waves within the surf zone, known as nearshore currents. These currents are independent of wind-driven surface currents. During winter, prevailing northerly winds generate counter-clockwise currents along the Romanian Black Sea coast, while during summer, southerly winds induce clockwise circulation patterns in the region. To understand nearshore currents, it is crucial to analyze wave conditions and nearshore bathymetry. Nearshore currents do not maintain a consistent pattern throughout the year; instead, their direction and velocity may fluctuate daily, depending on wave dynamics.

The level of the Black Sea fluctuates seasonally, in response to variations in freshwater inflow from its major tributary rivers (Stanev *et al.*, 2000), such as the Danube River. However, water level changes can be much more significant. Seasonal changes in wave energy and storm events, over imposed to human interventions (*e.g.* coastal defense structures) influence sediment deposition and erosion patterns within the bay. These factors result in a dynamic shoreline, where beach width and slope fluctuate over time.

2. MATERIAL AND METHODS

The research was carried out on board of an opportunity boat, 11-14 August 2020. A total of 65.3 km of geophysical measurement lines were recorded along 56 lines, distanced at 8-30 m, depending of the water depth. The measurement line lengths ranged between 550 m and 1.2 km (Fig. 2). For safety reasons, no bathymetric measurements in water less than 2.5 meters depth (about 50 meters from the shore) were undertaken, still given the sidescan sonar capabilities we recorded backscatter data up to 35-40 m from the shoreline.

2.1. GEOPHYSICAL MEASUREMENTS

The area was surveyed with a multibeam echosounder (MBES), a single beam echosounder (SBES) and a sidescan sonar (SSS). The MBES, model Norbit iWBMSh has a 200 KHz-700 KHz transducer emitting 256 or 512 acoustic beams. The MBES integrates a Motion Reference Unit (MRU) into the sonar head. The positioning and heading were assured by a RTK GNSS unit, model Trimble BD982. The accuracy of roll and pitch measurements, as measured by MVPOSView software, ranged from 0.01° to 0.03°, while the heading accuracy was 0.01°. The GPS horizontal error was reported to be less than 25 cm. The MBES was employed for water depth greater than five meters and recorded both bathymetry and backscatter during the survey. For depth below five meters, the bathymetry data was obtained with a SBES, model CeeLine with a 200 KHz transducer. In the whole area backscatter data from a Klein L3900 sidescan sonar was recorded. Positioning was done using differential GPS receivers with a maximum horizontal error of 1.5 m for both SBES and sidescan sonar, each equipment having their own GPS receiver, positioned above the transducer. Blue Marble Geographics Global Mapper software was used for positioning and navigation of the research vessel while for the data recording, we used Xylem Hypack Hysweep Suite (for MBES), Eye4Software Hydromagic (for SBES) and SonarPro (for SSS).

The bathymetry data from the single beam echosounder was recorded, processed and exported with Eye4Software Hydromagic software, while the multibeam echosounder data was first processed with Hypack Suite, MBMAX64. After spikes were removed the data was exported as XYZ data. The Hypack suite has the advantage of showing both bathymetry and backscatter data from multibeam recorded in the same file. All *.xyz data was imported in QPS Fledermaus software which was used to analyze data and create *.geotif files with a resolution of 10 cm/pixel. The backscatter data from the multibeam was processed using Geocoder from the Hypack Suite, while the backscatter from the sidescan sonar was processed and exported with Hypack Targeting and Mosaicking.

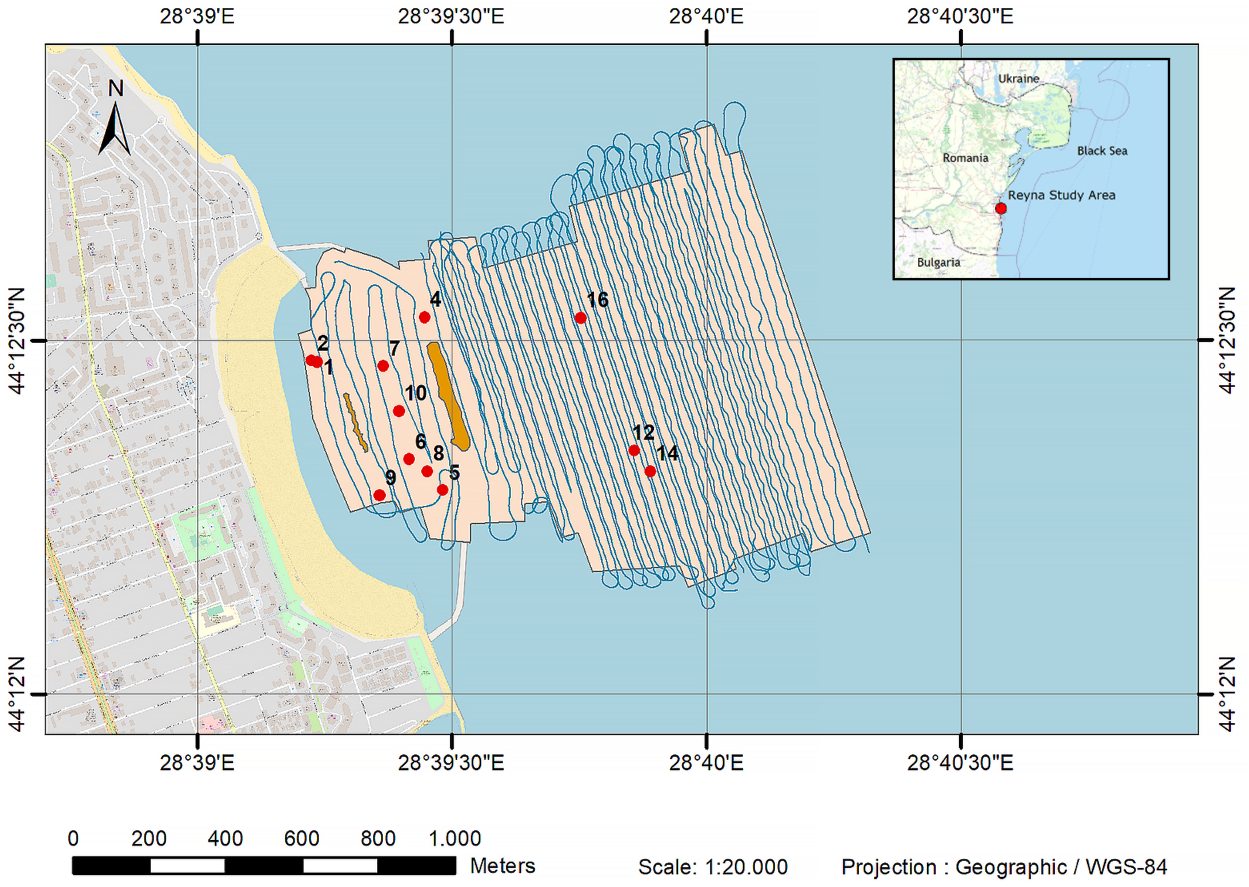

Fig. 2. Reyna study area. The blue line represents the track of the research boat, red dots are sampling locations, and orange areas are submerged dikes. Detail: study area location in the eastern part of Romania. Background map: OpenStreetMap.

Backscatter mosaics were created and exported as *.geotif files with a resolution of 10 cm/pixel. Two backscatter mosaics were created, from MBES and from SSS data. While the MBES data is more precise and contains more information regarding the signal strength that can be used for statistical analysis, the sidescan sonar backscatter is sometimes more representative, all terrain features being visually identifiable with greater accuracy. All geophysical data was integrated and analysed using Blue Marble Geographic Global Mapper, QPS Fledermaus and ESRI ArcMap software.

2.2. Sediment sampling

The sampling locations were established after the backscatter and bathymetry data were analyzed, allowing to cover all types of physical habitats we identified. Samples were collected for both sediments and biology in each sampling location. The sediment sampling was performed using a Van Veen grab (VVG) at the upper layer of the sediments and by SCUBA diving. The sediment samples were weighted on board the research vessel for the shell vs. sediment mass ratio. After the separation of the shell content, particle size analysis of the sediment samples was performed in the laboratory by the laser-diffractometry method using an analyzer Malvern Mastersizer 2000E. The diffractometer measures the percentages of sediment particles in the various dimensional classes in 0.0001-2.0 mm interval with an accuracy error of 1%. The separation of the granulometric classes was done to conform the Udden-Wentworth logarithmic scale (Udden, 1914; Wentworth, 1922): clay, silt, sand, and elements bigger than 2 mm, mainly represented by shells or shell debris. Sediment classification was performed/adapted using the Folk-14 diagram (Folk, 1954). The textural parameters were calculated using the GRADISTAT package for the analysis of unconsolidated sediments (Blott and Pye, 2001).

2.3. Biological sampling

The biological samples were washed, sorted and preserved on the field and analyzed in laboratory afterwards. The scuba diving activity consisted in observations of the fauna and sediments, especially on rock substrata. *Visual census* methods were applied to make high confidence observations of all encountered benthic habitats together with sampling collections by scrapping of rock epibenthic fauna (mussel beds especially) and excavations of marl beds.

2.4. Physical habitats map

In addition to mapping sea floor depth, the MBES system captures valuable data such as the backscatter intensity of the acoustic signal, which can be used to create a physical habitat map. The backscatter strength, measured in decibels (dB), was used to generate a referenced image (mosaic), where each pixel reflects a specific backscatter value. High dB values correspond to coarse materials, such as rocks or shell debris, which produce stronger acoustic reflections and appear as lighter areas in the mosaic. Conversely, low dB values indicate finer sediments, such as mud and sand, which are represented by darker shades.

Various techniques for sediment classification exist, each with its own advantages and limitations. For this study, four broad habitat classes were defined: sandy mud, sand, rocky bottoms (with two variations for limestone and marlstone) and mixed sediments (a mix of sand and shell debris). The distinction between limestone and marlstone was made only by visual census by divers. This classification approach was considered to be the most suitable for the investigated area.

The physical habitat map was created through a multi-step process, starting with the generation of the backscatter mosaic in Geocoder, followed by further processing in Esri ArcMap to assign sediment classes to each pixel. The backscatter mosaic was developed in Geocoder using bathymetric data processed through MBMAX64, along with snippet data from Hypack Suite. The resulting mosaic, exported as *.geotiff files, was imported into Esri ArcMap. Focal Statistics were applied to identify hard sediments (rock outcrops), while the Map Algebra-Raster Calculator function was used to process unconsolidated sediments (mud, sand, shell debris). The backscatter mosaic has a resolution of 0.1 meters per pixel, while the sediment cover map was produced at a resolution of 1.0 meter per pixel. The final step involved converting all raster layers into polygon layers for statistical analysis, which quantified the areas and percentages of each sediment type.

3. RESULTS

The study area is located near the shore, in waters with depths up to ten meters. Within the inner bay, the water depth is less than six meters, increasing with distance from the shore. In the outer area, water depth is shallower in the northern and southern sections, where rock outcrops dominate (six to eight meters, locally five meters), while in the centre of the area the water depth reaches 8-10 m.

Throughout the study area, rock outcrops, primarily composed of limestone, cover the largest surface (44.84%), followed by shell debris (27.57%) and sand with shell debris (25.25%). The sand and marlstone covered areas represent less than 0.2% each.

The infralittoral rocks found in the study area is part of the sediment cover which represents only 0.3% of the entire Romanian coast (Teacă *et al.*, 2006). They are home to a very diverse fauna and flora and are highly important for marine life functioning as a shelter for many species (Teacă *et al.*, 2020). Although the dykes covering 2.0% of the area are not a natural habitat, they could act like natural reefs, supporting similar flora and fauna associations to those found on natural rocky bottoms (Gomoiu, 1986, 1997).

In the outer bay, there is a clear correlation between water depth and sediment distribution. Finer sediments (sand) and mixed sediments dominate the deeper areas, while rocky bottoms are more prevalent in shallower waters (Fig. 3).

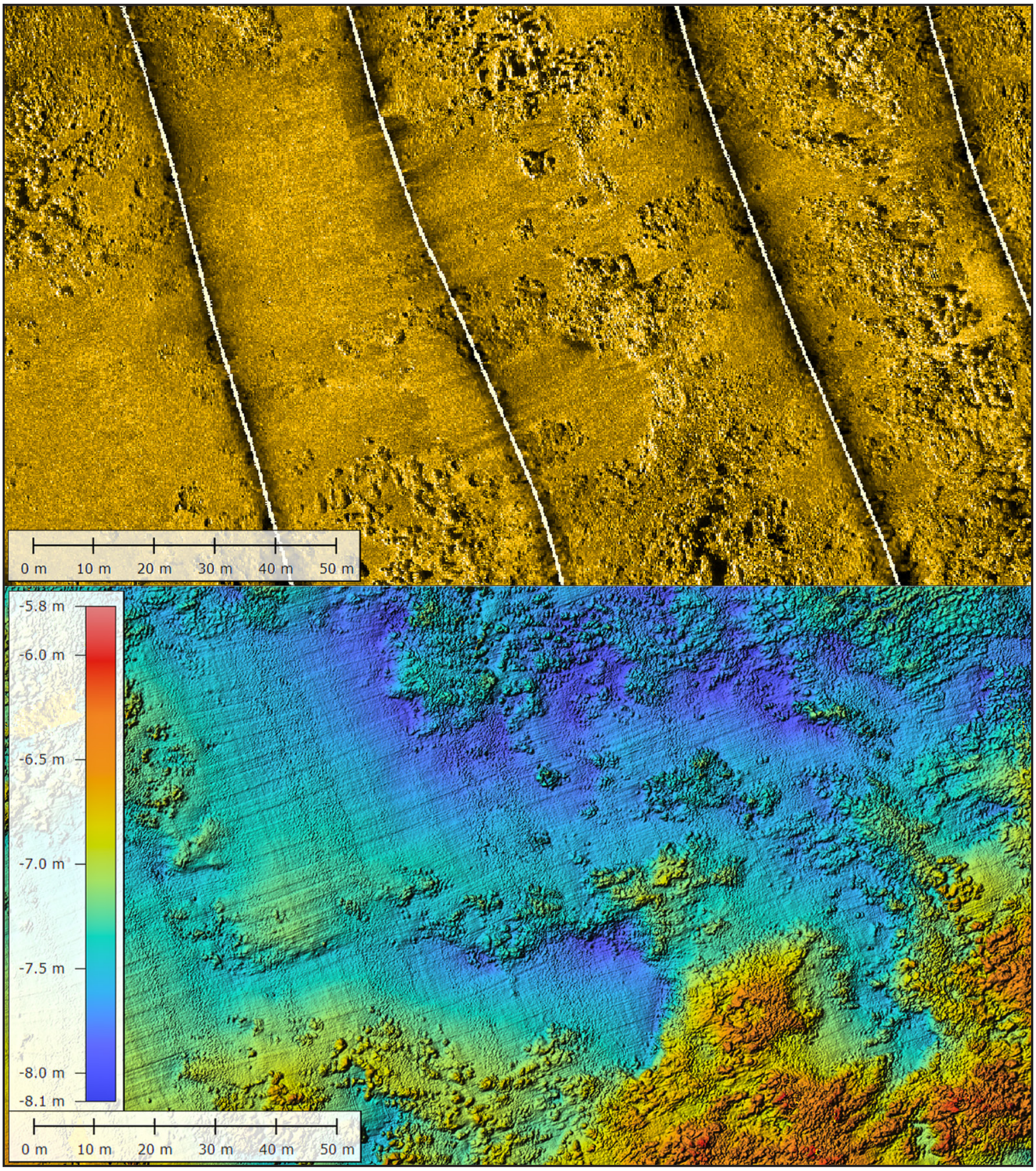

Fig. 3. Sand coverage and rocky bottom in the outer zone of the Reyna study area. The upper image shows the sidescan sonar mosaic, while the lower image presents the bathymetry map generated by the MBES.

Sediment and biology samples were collected by a van Veen grab, except the samples from the rock outcrops area (HCR-2, 4, 9, 12, 16) which were taken by divers only for biology. In the areas covered by unconsolidated sediments the samples revealed an important shell content: approx. 88% in sample HCR-14, 57% in sample HCR-05, 36% in sample HCR-07, and 24% in sample HCR-10, while the coarse fraction of sand is much more important than the finer one. The lower or higher content of shell debris could be differentiated on backscatter mosaic by the slightly darker or brighter colour tones. The sandy region adjacent to the southern embankment (sample HCR-08) is the only location where we found an exceptionally high sand content, exceeding 98%. In certain rocky bottom areas, a thin layer of primarily shell debris and sand covers the rocks. From these locations, both sediment and biological samples were collected by divers (HCR-06). The sediment from sample HCR-06 consists of more than 83% sand, while the shell content exceeds 15%. The sediment contents for all samples are shown in the Table 1.

Physical habitats

Based on the geophysical measurements, sediment sampling and visual census, five types of physical habitats were identified (Figs. 4 and 5, Tables 1 and 2):

- infralittoral rocks with biogenic reefs;
- infralittoral soft rocks (marlstone);
- infralittoral mixed sediments;
- infralittoral sand;
- infralittoral sandy mud.

Reyna area is divided into two distinct zones by the newly constructed submerged spur dike: the inner bay and the outer zone. These zones differ significantly in the sediment cover (physical habitats) percentage and the associated marine flora and fauna. The sea floor in the inner bay is predominantly covered by medium to coarse sand with shell debris (over 64%), followed by rocky (limestone) substrates, which account for 20% of the area and shell debris (5.7%). The coarse sand, primarily located in the northern and central sections of the inner bay, includes a significant fraction of shells, 24% in sample HCR-10 and more than 35% in sample HCR-07. In the southern region, the sea floor consists mainly of organogenic limestone interspersed with sand and shell debris, particularly near the embankment and in deeper areas. Distinct ripple marks are visible in the sandy and shell debris sediments, especially near the embankment and within the inner bay (Fig. 4). A small nearshore area (0.18%) is covered by marlstone. Near the southern embankment, sand sediments cover approximately 0.6% of bay's total area. This is the only area covered by such fine sediments and may be washed by the currents and waves in the future.

In the outer zone of the bay, rocky substrates dominate, covering 51% of the area. This is followed by shell debris (33.3%) and mixed sediments composed by sand with shell debris (14.5%). The rocky bottom is elevated by 0.5 to 1 meter relative to the surrounding seafloor. Sand covers a significant portion of the central outer area but does not appear in the southern section. The shell debris sediments are found mainly interspersed with the rock formations and form a transitional zone between the massive rock outcrops and areas covered by sand.

Table 1. Sediment samples in the study area

Sample	Latitude (N)	Longitude (E)	Water depth	Shells (%)	Sand (%)	Silt (%)	Mud (%)	Habitat type
HCR-02	44.20785	28.65373	3,3 m					Rocky bottom / marlstone
HCR-04	44.20888	28.65742	5.7 m					Rocky bottom / limestone
HCR-05	44.20480	28.65802	4.8 m	57.40	42.52	0.04	0.04	Shell debris with sand
HCR-06	44.20553	28.65693	4,6 m	15.54	83.42	0.54	0.50	Rocky bottom / limestone
HCR-07	44.20773	28.65607	4.7 m	35.70	63.30	0.52	0.48	Sand with shell debris
HCR-08	44.20525	28.65752	4.3 m	1.36	98.14	0.26	0.24	Sand
HCR-09	44.20468	28.65595	2.7 m					Rocky bottom / limestone
HCR-10	44.20667	28.65658	4.9 m	23.97	60.91	7.92	7.20	Muddy sand with shell debris
HCR-12	44.20574	28.66430	7.0 m					Rocky bottom / limestone
HCR-14	44.20525	28.66483	8.2 m	87.97	12.01	0.01	0.01	Shell debris with sand
HCR-16	44.20886	28.66254	7.0 m					Rocky bottom / limestone

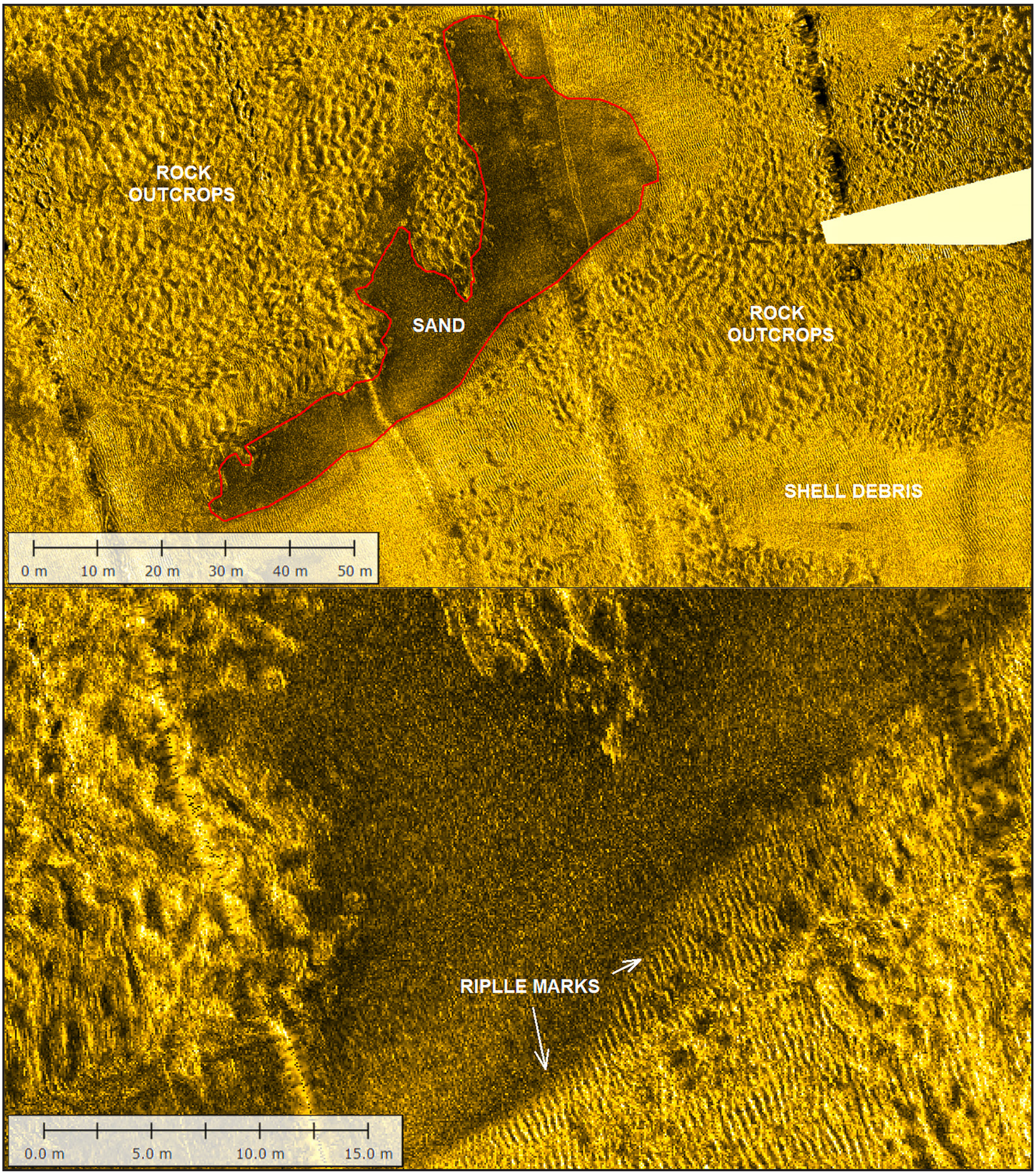

Fig. 4. Reyna study area, inner bay. Sidescan mosaic with the physical habitats in the inner bay. In the upper image infralittoral sand, infralittoral sandy mud and the rock outcrops may be distinguished while the lower image present a zoom-in area showing distinctive ripple marks covering the sandy bottom.

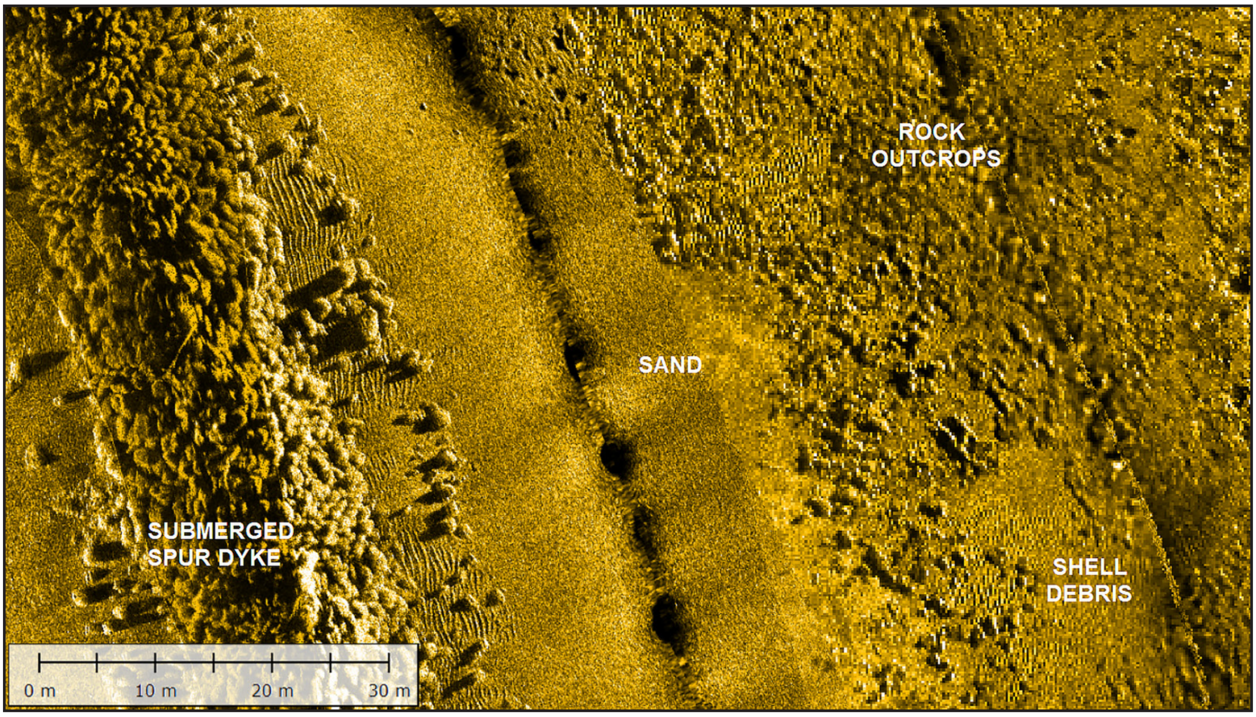

Fig. 5. Outer area of the Reyna study area. The sidescan mosaic displays a portion of the outer bay, with the submerged spur dyke visible on the left side separating it from the inner bay. Sand covers the region adjacent to the spur dyke, while the right side is dominated by rock outcrops interspersed with shell debris and sand.

Table 2. Sediment coverage in the study area

Sediment type	Coverage (km^2)	Percent (%)
Sand	0.001412	0.13
Sand with shell debris	0.277731	25.25
Shell debris	0.303202	27.57
Rocky bottom / limestone	0.493094	44.84
Rocky bottom / marlstone	0.001994	0.18
Dykes	0.022349	2.03
Total	**1.099782**	**100**

The shell debris sediments contain varying proportions of shells (88% in sample HCR-14) and sand, with minor amounts of silt and mud. These extensive rock outcrops are found primarily in the northern, eastern, and southern parts of the outer bay.

Macrozoobenthic communities

The visual census showed that the communities in the study area belong to the infralittoral biozone. The macrozoobenthic communities were represented by 15 species, belonging to five major taxonomic groups.

Based on the multivariate analyses combined with the biotic and abiotic parameters directly observed on the field five communities were distinguished (Fig. 6):

1. Infralittoral with coarse biogenic sediments with diverse fauna (nereididae polychaetes, *Diogenes pugilator, Chamelea gallina*).
2. Infralittoral with sandy sediments with a moderate content of shelly material with diverse fauna (*Chamelea gallina, Diogenes pugilator*).
3. Infralittoral with marl beds (*Pholas dactylus, Brachynotus sexdentatus, Rapana venosa, Palaemon elegans, Xantho poressa).*
4. Infralittoral rock with photophilous algae and molgulides (biogenic reefs with *Mytilus* and *Mytilaster*, *Pilumnus hirtellus, Rapana venosa*).
5. Infralittoral rock with endolithobiont mollusks (*Petricola lithophaga, Pilumnus hirtellus, Rapana venosa*).

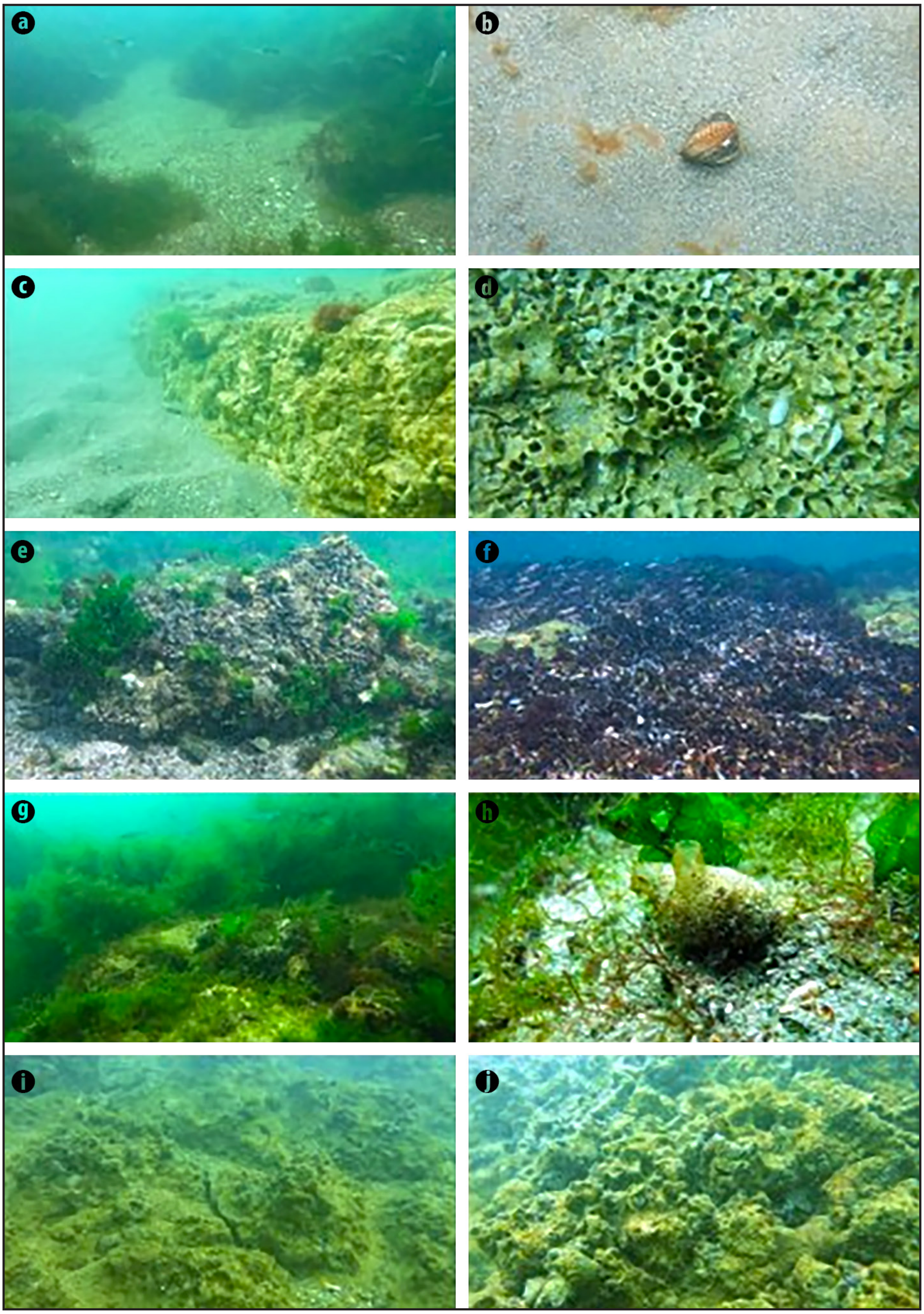

Fig. 6. Benthic communities (photo: Adrian Teacă). (**a**) – Infralittoral with coarse biogenic sediments with diverse fauna (nereididae polychaetes, *Diogenes pugilator, Chamelea gallina*); (**b**) – Infralittoral with sandy sediments with a moderate content of shelly material with diverse fauna (*Chamelea gallina, Diogenes pugilator*); (**c**, **d**) – Infralittoral with marl beds (*Pholas dactylus, Brachynotus sexdentatus, Rapana venosa, Palaemon elegans, Xantho poressa);* (**e**, **f**, **g**, **h**) – Infralittoral rock with photophilous algae and molgulides (biogenic reefs with *Mytilus* and *Mytilaster*, *Pilumnus hirtellus, Rapana venosa*); (**i**, **j**) – Infralittoral rock with endolithobiont mollusks (*Petricola lithophaga, Pilumnus hirtellus, Rapana venosa*).

Infralittoral with marl beds is home to species like the endangered piddock (*Pholas dactylus*), protected under Order no. 488/2020, as well as other associated species, including the crab *Brachynotus sexdentatus* and various macrophytes. These were accidentally discovered in 2018 (Teacă A., pers. comm.) during diving in the area. They are located in the coastal area, at a depth of 3 m, with an area of about 0.002 km^2 with a length of 108 m (parallel to the shore) and an average width of 20 m.

Bathymetric, Sidescan and Habitat Map Summary

The bathymetric analysis (Fig. 7) illustrates the spatial distribution of water depths, highlighting the dominance of rocky outcrops. This bathymetric distinction aligns well with the geophysical and biological findings, particularly the correlation between sediment types and depth. The sidescan mosaic (Fig. 8) provides an in-depth visual representation of the seafloor's heterogeneous nature, showcasing the variation in sediment composition. Notably, the mosaic captures the differences in backscatter intensity, which further aids in distinguishing areas of high shell content and coarser sediments from finer sandy regions. The physical habitats map (Fig. 9) underscores the diverse habitats found within the study area, from rocky infralittoral zones with biogenic reefs to mixed sediments and sandy mud areas.

4. DISCUSSIONS AND CONCLUSIONS

The extensive survey conducted in August 2020 offers significant insights into the sediment distribution and habitat characteristics of the Romanian Black Sea coast. The study area, spanning from shallow inner bays to deeper outer zones, revealed a diverse range of sediment types and physical habitats. Geophysical and biological data collection using advanced technologies, including multibeam and single beam echosounders, and sidescan sonar, provided a detailed mapping of the seafloor. The resulting lithological assessment identified limestone rock outcrops as the predominant feature, covering over half of the study area followed by shell debris and sand.

The sediment analysis showed that coarse materials dominate, with sediment composition varying significantly across the study area. In the inner bay, medium to coarse sand is predominant, while the outer bay is characterized by extensive rocky substrates, with significant areas covered by shell debris. Notably, the inner bay also features unique marlstone habitats that support protected species such as *Pholas dactylus*.

The physical habitat mapping revealed five distinct habitat types: infralittoral rocks with biogenic reefs, marlstone, shell debris, sand with shell debris, and sand. These habitats exhibit different faunal and floral associations, reflecting the variability in sediment composition and depth.

In a natural habitat, the distribution of the sediment cover is directly dependent of erosional and depositional processes as well as the underlying morphology shaped during the last glaciation, when the shelf surface was exposed. Sediment starving of beaches on Romanian coast is a known issue, well documented, as fine sediments are prone to be washed by waves and currents. In our case study, the natural habitat was much affected by human interventions in recent years: the beach nourishment with coarse sand and shell debris and the construction of the submerged dykes (old and new one) and north and south embankments. A clear difference between the inner bay and outer zone related to the sediment cover percentages is now recorded. The inner bay is protected by the new constructions while the outer bay is much more exposed to waves and currents action and thus prone to changes in sediment cover.

Rocky bottom areas occur in the most part of the study area. They are a hotspot of diversity in terms of marine biota, both fauna and flora and have a limited occurrence in the northern part of the Romanian Black Sea coast. The amalgam of rock outcrops are interspersed with shell debris and sand and have a high degree of heterogeneity. The sand cover is more stable in the inner bay due to protection against the water currents and waves. In the outer bay the sand cover is found primary in line with the submerged dyke, perpendicular on shore, while in other parts is less prevalent. This may be due to the protection which these constructions offer against waves and currents disturbing the natural flow of the water and modifying the erosion/deposition processes and the sediment transport and reposition. The ripple marks made by water currents suggest east-west current flow, highlighting the direction of sediment transport especially in unprotected areas. Sediments with a high content of sand occur in a very small area, surrounded by rocky outcrops and shell debris with ripple marks thus being prone to erosion by bottom currents. The marlstone near shore offers a small but unique area, which was found to host protected species (*Pholas dactylus*). The submerged dykes and the embankments mimic natural reefs, supporting a similar flora and fauna associations. These findings underline the complex interaction between natural forces and human alterations in coastal environments, requiring careful future management.

Overall, our study highlights the complex interplay between natural sediment processes and human interventions, underscoring the need for continued monitoring and management to preserve these critical coastal habitats. The findings contribute to a deeper understanding of the marine environment and help strategies for its conservation.

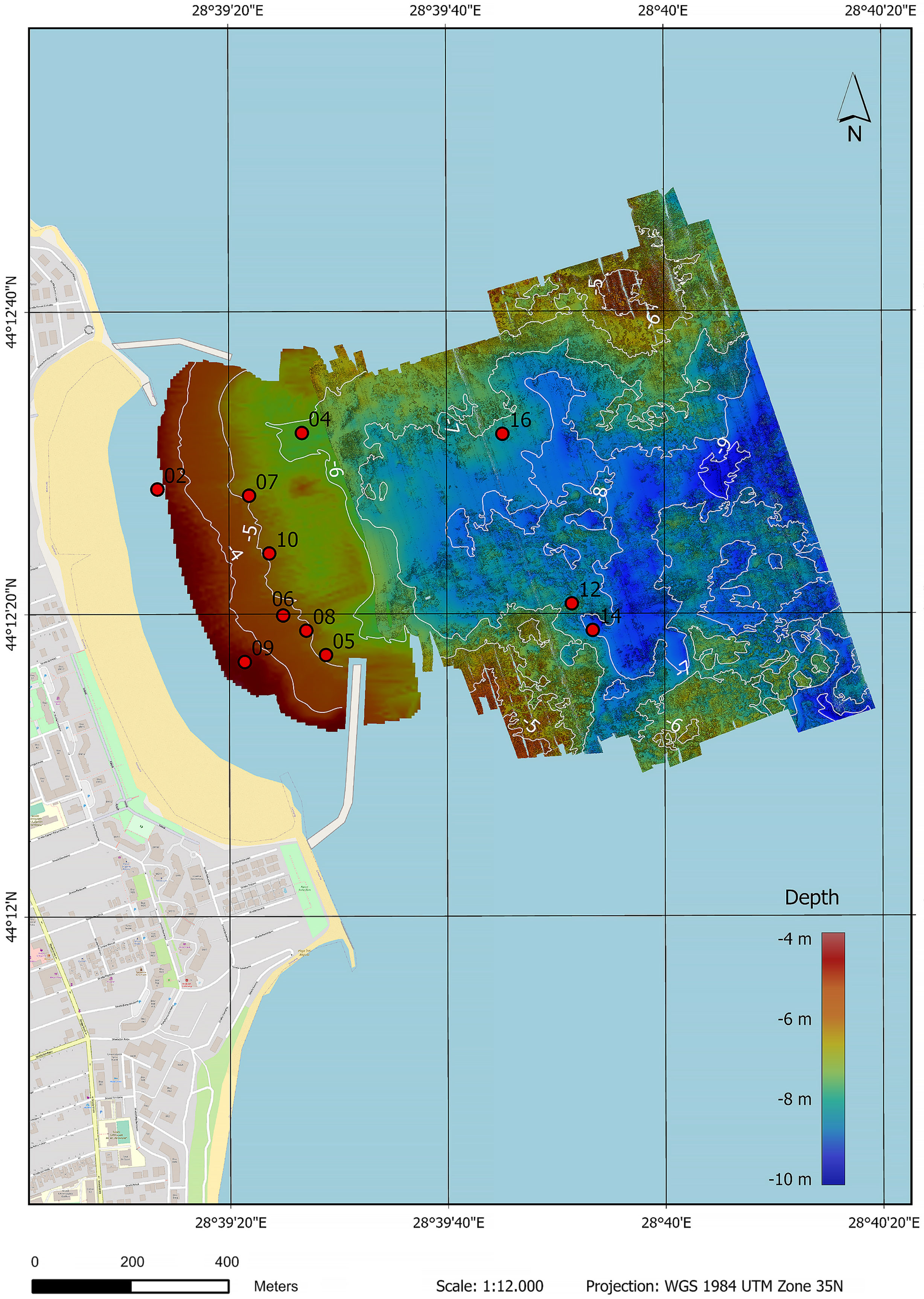

Fig. 7. Bathymetric Map of the Reyna study area.

Fig. 8. Sidescan Mosaic of the Reyna study area.

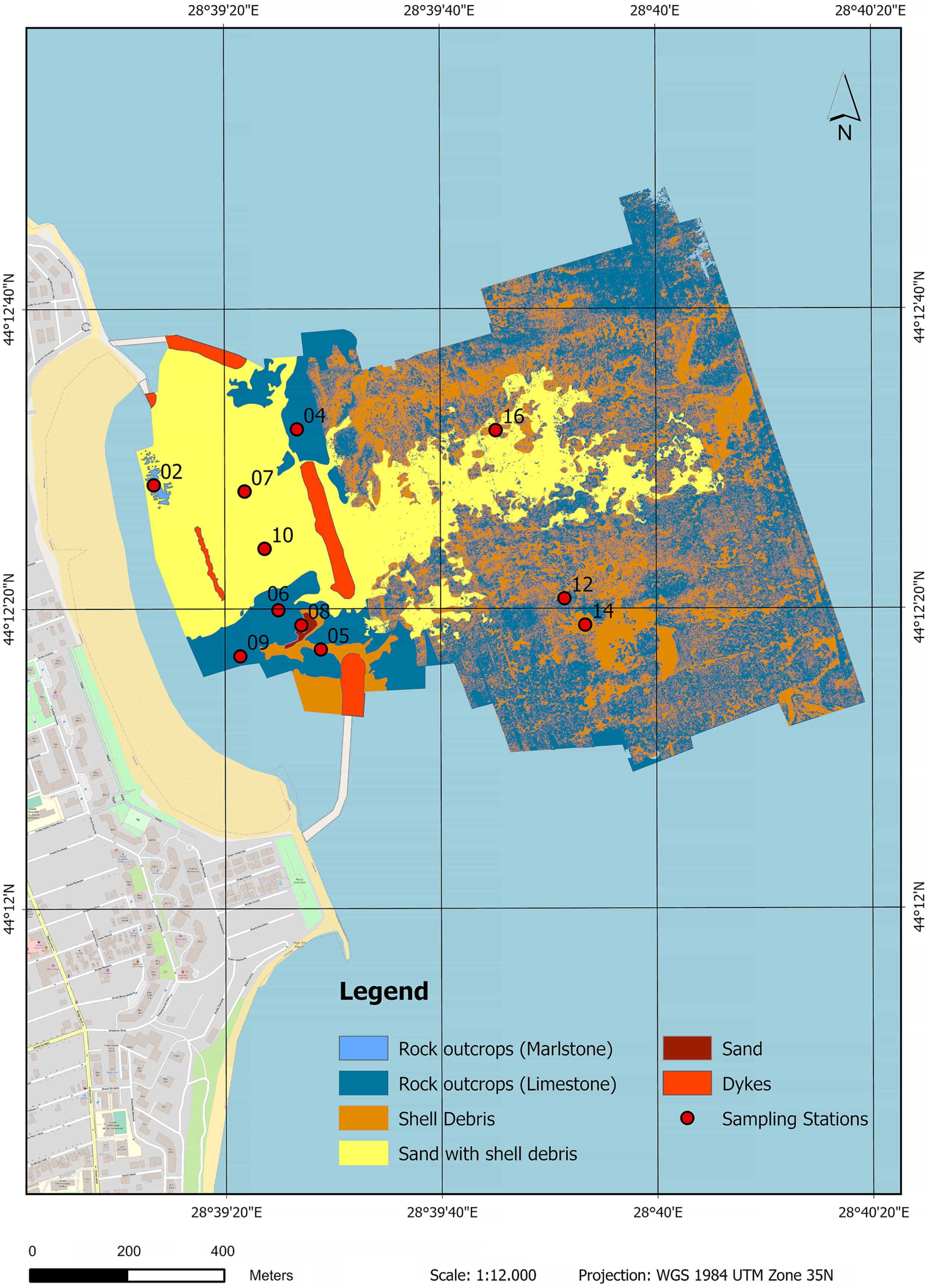

Fig. 9. Physical habitat map of the Reyna study area.

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