Environmental characterization of a dredging disposal site on the continental shelf of Espírito Santo, Brazil

Caracterização ambiental de área para descarte de material dragado na plataforma continental do Espírito Santo, Brasil

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Abstract

Dredge material placement is among the major problems in coastal management. Sedimentation caused by dredge-spoil disposal presents a series of impacts, including the burial of benthos and the suffocation of filter-feeding benthic organisms. To minimize dredging impacts, studies in dredging disposal sites shall be performed to allow better approaches to adverse ecological risks. The goal of the present study was to map the sea bottom environment of a potential dredge disposal site by performing its geomorphology and ecology characterization, in the continental shelf of Espírito Santo state. Acoustic images were obtained using side scan sonar to characterize sediment texture and the geometry of deposits, along with a bathymetric survey. Additionally, underwater footage provided images and the description of the biota communities. The bathymetric survey revealed a relatively plain and homogenous bottom, with the presence of a paleochannel. Smooth elevations, with approximately 0.50m high, were found and characterized as calcareous biogenic concretions, among benthic and nektonic organisms. The organisms revealed a heterogeneous composition and a scattered distribution throughout the sampling stations, with the presence of a threatened species.

Keywords: paleochannel; benthic organisms; coastal management; side scan sonar; bathymetry

Resumo

O descarte de material dragado está entre os principais problemas no gerenciamento costeiro. A sedimentação causada pelo despejo do material dragado apresenta uma série de impactos, incluindo o soterramento e o sufocamento de comunidades bentônicas e organismos filtradores. Para a minimização dos impactos, estudos em áreas de descarte para a avaliação de riscos ecológicos devem ser realizados. O objetivo desse estudo foi mapear o fundo marinho de uma potencial área de descarte de material dragado através de sua caracterização geomorfológica e ecológica, em ambiente de plataforma continental do estado do Espírito Santo. Foram obtidas imagens acústicas por meio de sonar de varredura lateral para a caracterização da textura sedimentar e da geometria dos depósitos, junto com levantamento batimétrico. Além disso, filmagens submarinas proporcionaram a descrição da comunidade biótica. O levantamento batimétrico revelou fundo relativamente plano e homogêneo, com a presença de um paleocanal. Elevações suaves com aproximadamente 0,50m de altura foram observadas e caracterizadas como concreções calcáreas biogênicas, junto de organismos bentônicos e nectônicos. Os organismos revelaram-se heterogêneos em sua composição e tiveram distribuição esparsa ao longo das estações de amostragem, ressaltando a presença de espécie ameaçada de extinção.

Palavras-chave: paleocanal; organismos bentônicos; gerenciamento costeiro; sonar de varredura lateral; batimetria

1. Introduction

Coastal areas have been considered fundamental along with human history as a source of water, food, and healthy environment for living. Further, these areas are also gateways for maritime trade and major cities to develop along the shore. Nowadays, approximately two-thirds of the world's population is in the relatively narrow coastal belt and about 6.3 billion people are expected to be living in coastal areas by the year 2025 (UNEP 2003).

The continuous human population growth puts at risk the fragile balance of the marine coastal environment. Thus it is imperative to consider the environmental aspects when designing an enterprise, be it of any nature. Dredging activities are carried out to maintain navigation in ports, harbors, and channels as well as for the development of such facilities. On the other hand, the removal of sediments can cause adverse impacts on marine species and habitats. The impact may be due to physical and/or chemical changes in the environment at the disposal site. The excavation, transportation, and disposal of soft-bottom material may lead to various harmful effects on the marine environment, especially when carried out near sensitive habitats such as the benthic environment (PIANC 2010).

The major human impacts on the benthic ecosystem are mostly associated with the increase in sedimentation due to dredging activities and the discharge of industrial and urban effluents. In this perspective, it is recommended that the marine areas be investigated, mapped, and monitored through high-resolution geophysical methods and other kinds of approaches.

The purpose of the present study was to characterize the physiography of the seafloor and its ecological importance in a potential dredged residue disposal site, in the inner continental shelf of the state of Espírito Santo (SE Brazil), through the interpretation of geophysical data and biological observation.

2. Study site

Bastos *et al.* (2015) characterized the Espírito Santo continental shelf morphology and identified three major sections: Abrolhos shelf, Doce river shelf, and Paleovalleys shelf. The area of the current study is situated on the Paleovalleys shelf, where low sedimentary input and erosive processes characterize its morphology, with associated hardbottoms and relict features such as unfilled and partially-filled paleovalleys.

According to Brehme (1984), the Espírito Santo shelf exhibits an average steepness of 1:600 and presents morphology cut by several incised valleys. The presence of carbonate sedimentation on the continental shelf of Espírito Santo was reported by Kowsmann & Costa (1979), which observed carbonate contents reaching more than 75% of concentration in sediments.

In relation to hydrodynamics, the study area is submitted to a micro-tidal regime ranging from 1.40 to 1.50m, as it is classified as dominated by waves, with wave heights ranging from 0.60 to 0.90m with peaks of 1.50m (Albino *et al*. 2001).

This region presents large fields of oil located in the Campos and Espírito Santo Basins. Also, this area embraces the largest harbor of the Espírito Santo state (Vitória and Tubarão harbors), responsible for the shipping of a large portion of Brazilian minerals and cellulose. Other important activities related to the area are fishing and tourism.

The study site is localized Southeast to the city of Vitória, the capital of Espírito Santo state, and comprises an area of 30.20km² (Figure 1). The area was defined by Companhia Docas do Espírito Santo (CODESA) for the evaluation of a possible dredging disposal site for sediments originating from dredging activities of the Vitória harbor complex.

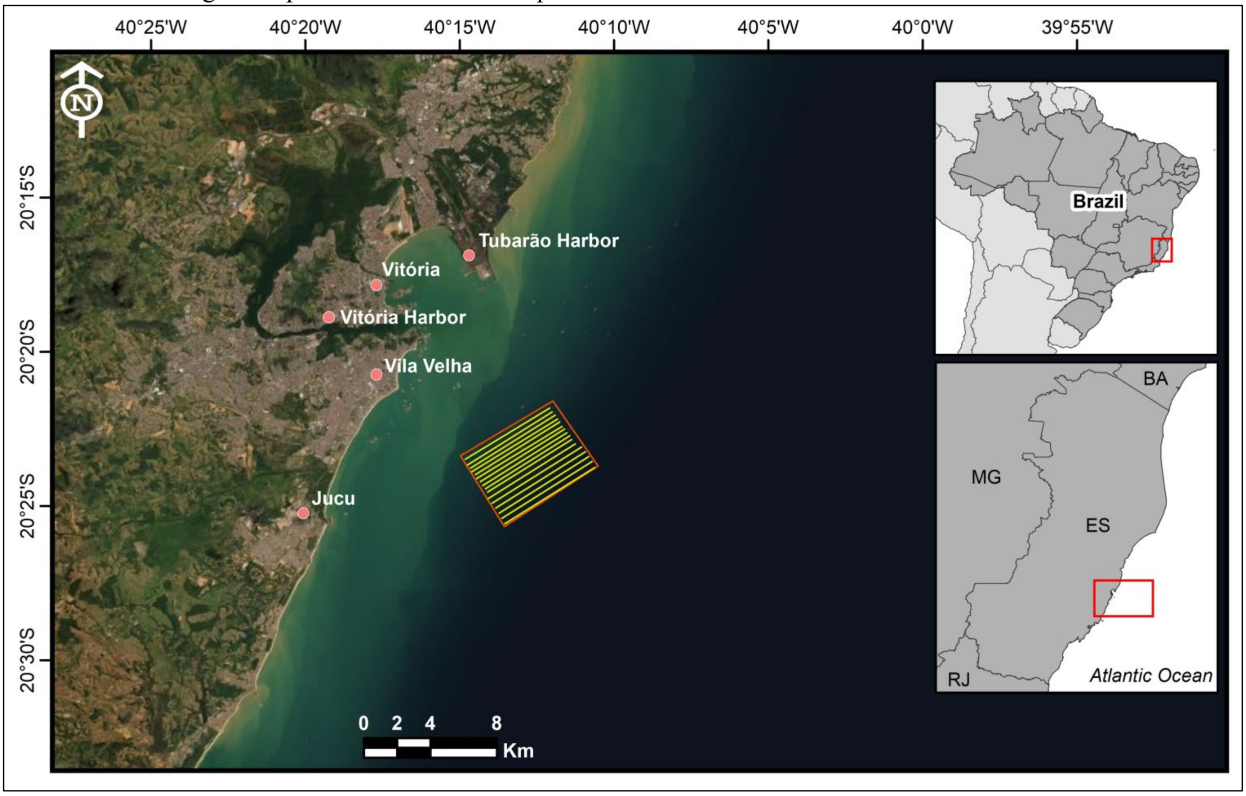


Figure 1: The map shows the limits of the surveyed area in orange and the navigation lines in yellow. The region has an area of 30.20km², on the Espírito Santo inner continental shelf.

3. Material and methods

3.1. Acoustic geophysical data

Side scan sonar and bathymetric data were collected simultaneously to characterize the seabed morphology, gathering information of altimetry values, sedimentary facies, and geometry of the seafloor deposits. Surveys were performed during the summer of 2016, between February 23 and 26th. Navigation lines were planned and performed in SW-NE direction due to favorable winds and to avoid the presence of a great number of anchored ships in the region. Spacing between navigation lines ranged from 250 to 340m, depending on average depth.

The seafloor depth was measured using a single beam echo-sounder (OHMEX Sonarmite) operating in 235KHz frequency, combined to a NOVATEL DGPS system (differential corrections provided by satellite, with sub-metric precision), connected to the Hypack® software, where the navigation and tide corrections were applied simultaneously to the data acquisition, according to the Hydrography and Navigation Board (DHN, Marinha do Brasil) survey standards. The tide correction was based on the Vitória Harbor tide gauge station.

After processing the raw bathymetry data by eliminating spikes on Hypack®, a text file (.xyz) holding seabed height values with their respective coordinates was generated. Then, a bathymetric map was produced using Geosoft® software. The interpolation method applied was the Inverse Distance Weighting (IDW).

Also, regional bathymetric quotes of the Espírito Santo Continental Shelf were represented from the combination of vectorized sounding charts numbers FB 1410-001-75 and FB 1410-003-75, available at DHN.

The seabed imaging was carried out using the EdgeTech®4100 side scan sonar system, with a 272-TD sensor. The beam width was 300m for depths equal or less than -30m (150m of range), and, for depths below -30m, the beam width was 400m (200m of range).

Data were processed using GeoSurvey™ software, with a resolution of 1m/pixel, to produce a sonographic mosaic. Just as the bathymetry data, side scan sonar images were georeferenced through a DGPS system. For the interpretation of the images, Geosoft® software was used to improve details and generate the sonar Mosaic.

It is important to emphasize that the acoustic signal which returns to the side scan sonar transducer depends on backscattering and specular reflections, which in turn, depends on seabed composition (Johnson & Helferty 1990), and is directly related to the interpretation of the intensity of the acoustic signal. Acoustic shades observed on sonar images allowed the estimation of bedform height (h), through the trigonometric principle in the equation (Blondel 2009):

$$(1)\ h = \frac{\Delta R \times H}{R}$$

Where ΔR is the length of the shadow zone; H is the altitude of the sonar above the seabed; R is the maximum range distance.

In addition, a sonogram image of Jucu river paleochannel was deployed from a dataset obtained by Dias & Pereira (1996) at the REVIZEE Program (Programa de Avaliação do Potencial Sustentável de Recursos Vivos na Zona Econômica Exclusiva). This specific database was not georeferenced, whereas the acquisition system of the survey from REVIZEE was analog.

3.2. Seafloor video records

After acoustic geophysical data analysis, five divers performed underwater video inspection of the seafloor with two cameras (GoPro and Nikon cameras) and collected surface sediment samples in ten selected targets in the shallowest areas. Images were obtained throughout those videos to recognize seabed characteristics and faunal spots. The evaluation of the video records resulted in a list of organisms, identified to the lowest taxonomic level, whenever possible.

4. Results

The bathymetric data presented a variation in depth between -33 and -43m and a regional gradient of 1:700. The deepest areas are located at the Eastern and Southern portions (Figure 2).

Greater contrasts on the seabed topography are evident on the edges of the area. Southwards, there is a bathymetric depression that reaches -43m depth. Figure 3a presents a regional bathymetric overview where the paleochannel of the Jucu river was considered, by size, the most evident feature in the region. Figure 3b shows the side scan sonar image of the same paleochannel, obtained during a survey executed by the REVIZEE Program. The -43m depression found southwards of the study area is apparently connected to the Jucu river paleochannel.

The side scan sonar mosaic shows the sedimentary types, geometry, and distribution over the area. It was observed two different patterns regarding to backscatter intensity: dark grey patterns, which here are associated to high reflectivity of acoustic signal; and light grey, related to low energy of the received acoustic signal (Figure 4).

From the validation of sonar backscattering patterns, throughout video observation and sediment samples, it was possible to infer the presence of concretions. The sedimentary facies presented on the facies map (Figure 4) show typically sandy/muddy spots along the area, with the occurrence of sandy mud, concretions, and mud patterns (some mud areas are also combined with sands in smaller quantities) – see Table 1. The association of sonar and bathymetry data with the video recordings allowed to confirm the presence of biogenic carbonate concretions among benthic organisms in relatively shallower relief, mostly in the Northeastern area (Figure 5). Shades observed on sonar images (also seen in Figure 5) allowed the estimation of height of those structures in approximately 50cm.

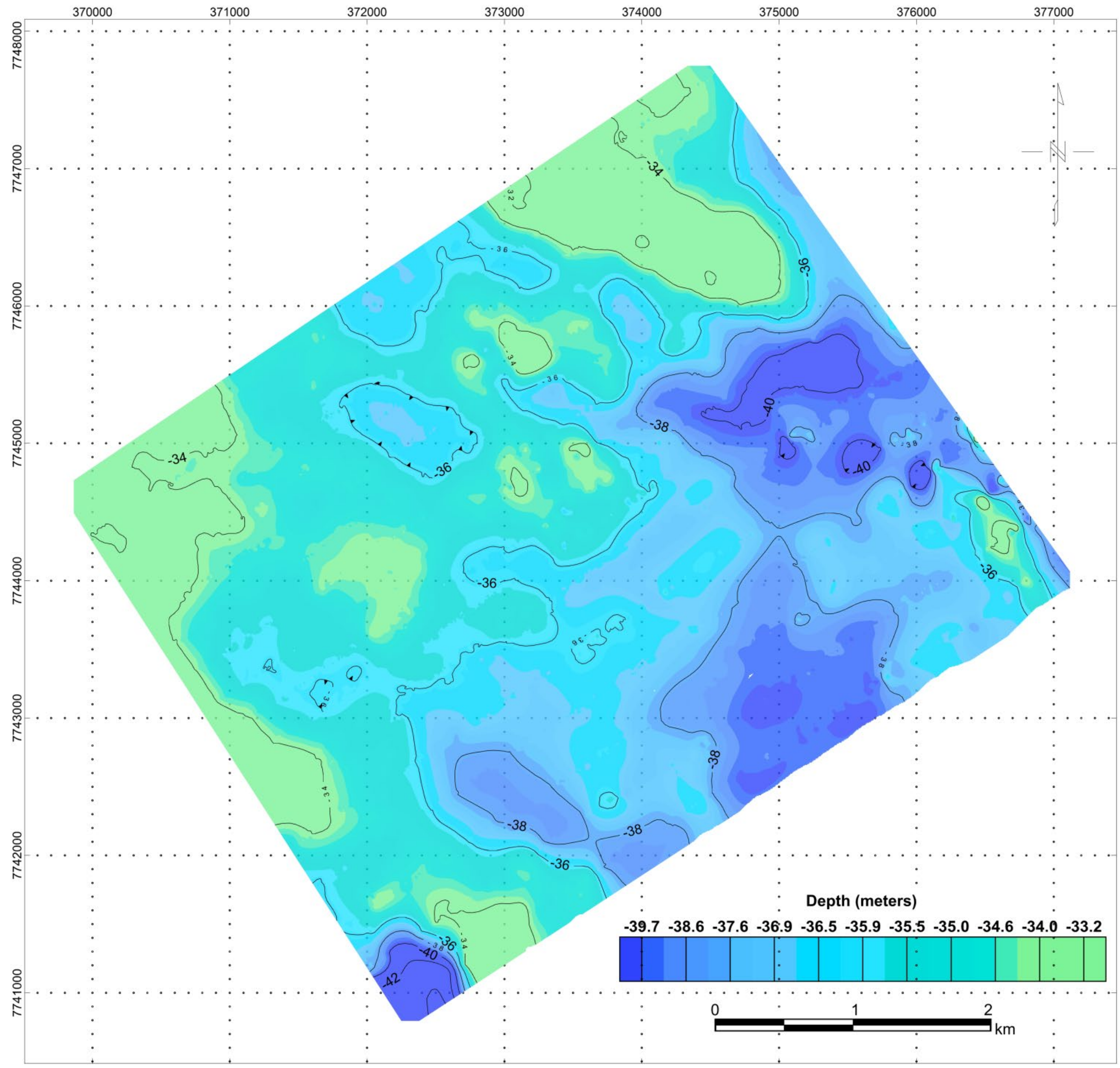


Figure 2: Bathymetric map of the study area. Variance in depth shows a relatively flat surface.

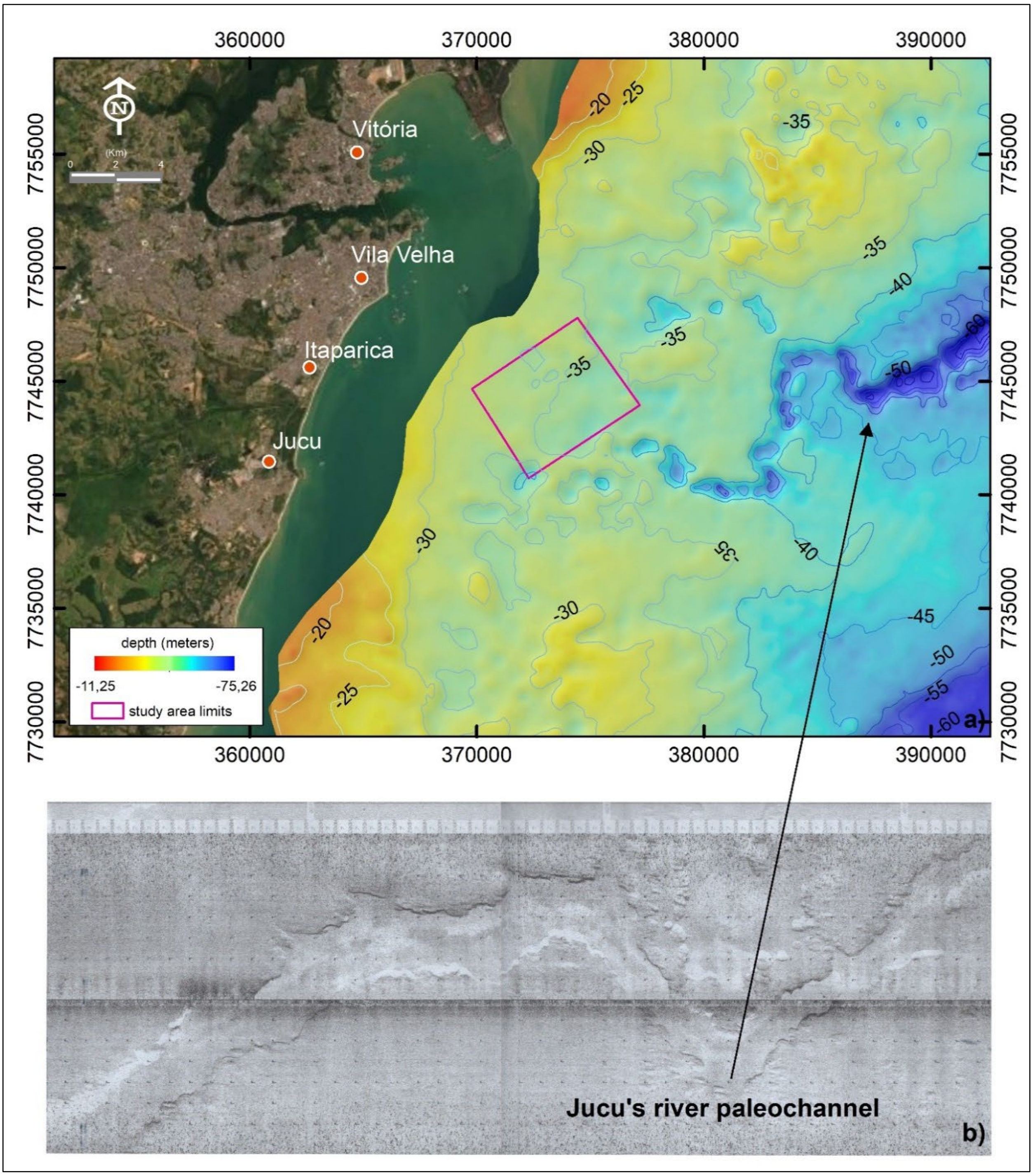


Figure 3: (a) Bathymetric regional overview of the Espírito Santo Continental Shelf (from DHN sounding charts) and study area limits. (b) The side scan sonar image of Jucu river paleochannel obtained by the REVIZEE Program (Dias & Pereira 1996).

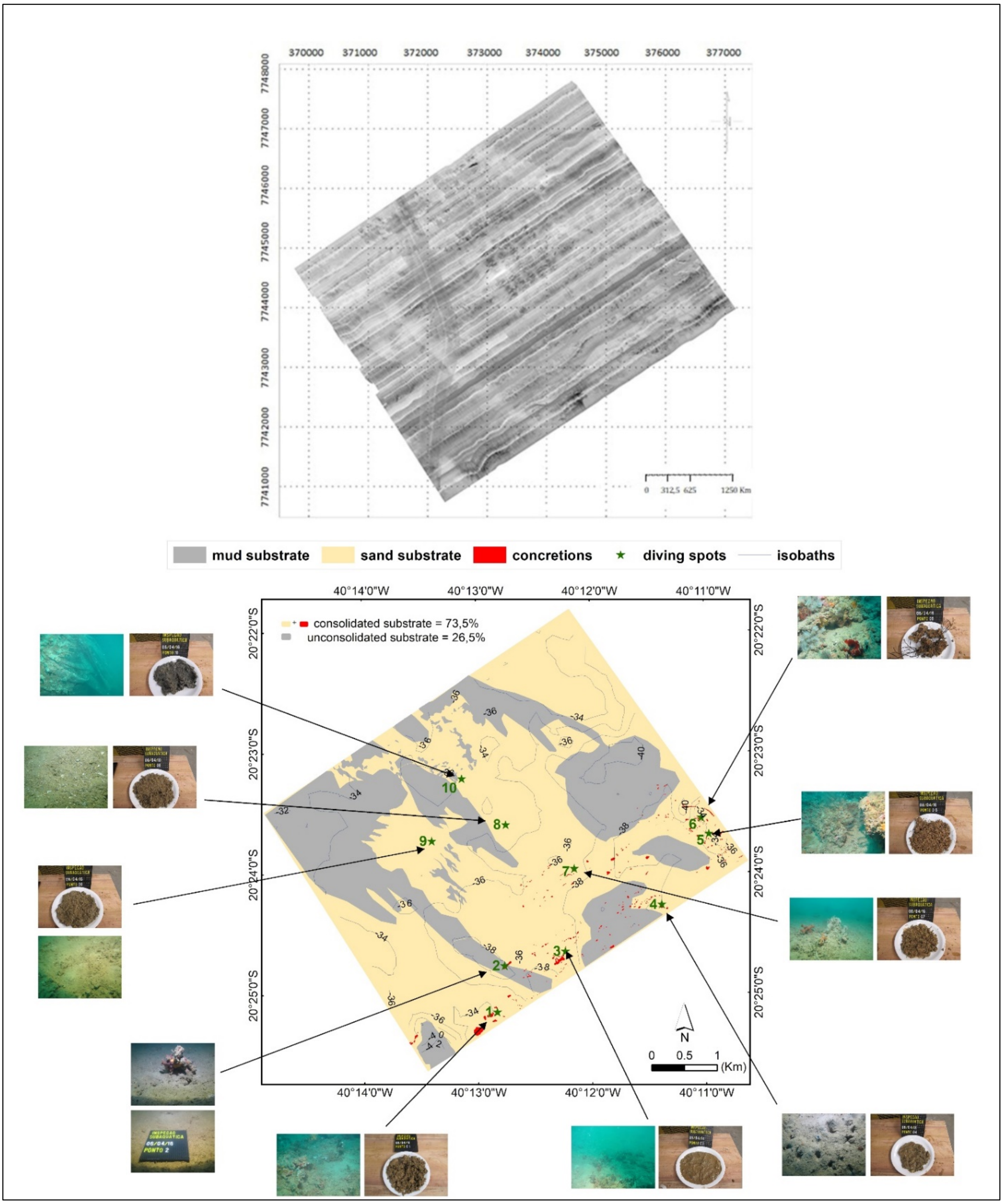
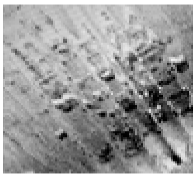
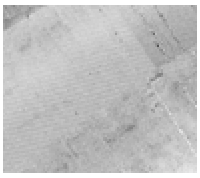
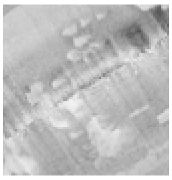
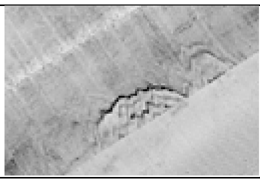


Figure 4: Side scan sonar mosaic of the study area (up). Facies map interpreting sonar records with the location of diving spots and their respective screenshots from subaquatic filming, representing sedimentary and biota from each selected location (down).

Table 1: Representation of acoustic facies on sonograms and their respective characterization, according to the related area, presented on the mosaic of the study area.

Area of the Mosaic	Acoustic Facies	Sediment Sample	Interpretation
Central			Muddy sands and hard muds
East			Presence of biogenic carbonate concretions
Central			Sandy muds
North-West			Soft muds
Over the entire area		-	Ships interference on side scan sonar data

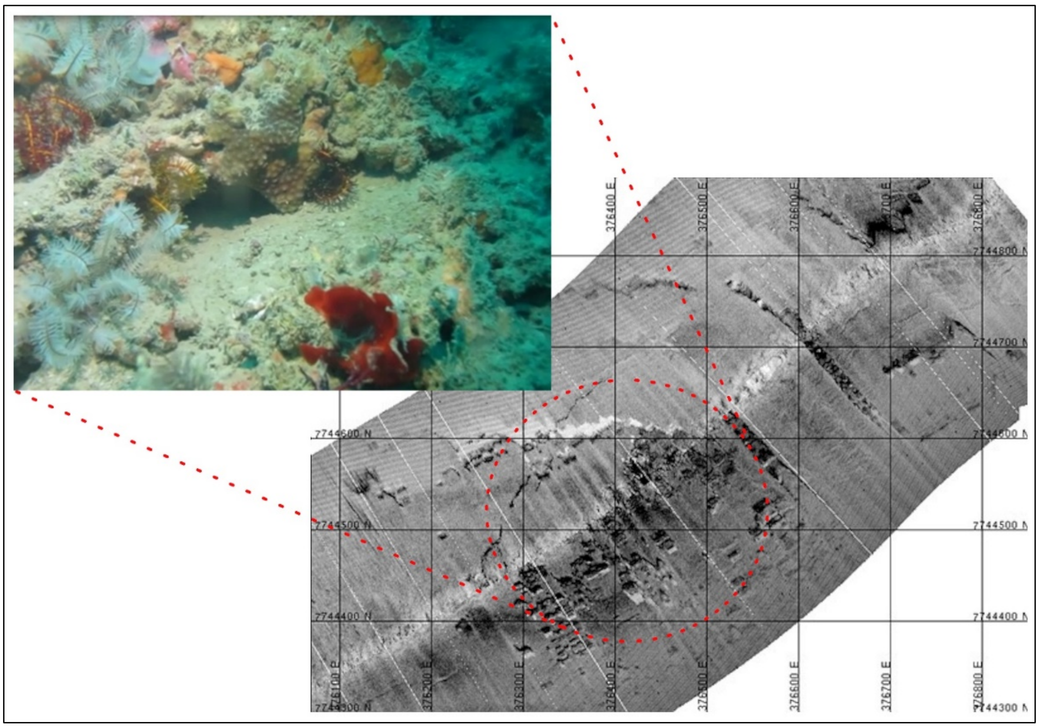


Figure 5: The image on the left illustrates the occurrence of benthic organisms, at diving point number 6 (through video analysis).

Dark grey patterns are observed in most of the sonar images, characterizing strong acoustic reflections of the bottom, which were associated to muddy sands, hard mud (i.e. mud that presented higher stiffness) and/or biogenic carbonate concretions. On the other hand, light grey colors showed lower acoustic reflection and were correlated to sandy muds and/or soft mud, corresponding to loose sediments. Those muds are related to white tracks with linear limits in NW-SE direction that cross the entire area, which can be suggestive of the presence of estuarine sediment deposits that experienced linear stream transportation, predominantly in that same direction (see in Figure 4). Considering the strong acoustic reflection of the large ships that were present while acoustic data were acquired, a few segments on the side scan sonar mosaic turned up to be highly reflective.

The estimated area for the consolidated substrate (e.g. hard mud and/or biogenic carbonate concretions) was 22.2km² (ca. 73.5% of the whole area), while unconsolidated material (e.g. sandy muds and/or soft mud) represented an area of 8km² (ca. 26.5%).

The analysis of underwater video images led to the taxonomic identification of different benthic and nektonic organisms. It was possible to identify at least five Cnidaria, two Echinodermata and four Chordata specimens. The geographic coordinates (based on datum WGS 84) for each selected spot of underwater video inspection are presented in Table 2. Further, Table 3 shows the related organisms list.

Table 2**:** Diving spot numbers and their respective geographic coordinates.

Diving spot	Latitude	Longitude
1	20° 25' 10"S	40º 12’ 50”W
2	20° 24' 47"S	40° 12' 46"W
3	20° 24' 40"S	40° 12' 14"W
4	20° 24' 17"S	40° 11' 23"W
5	20° 23' 42"S	40° 10' 58"W
6	20° 23' 34"S	40° 11' 02"W
7	20° 23' 59"S	40° 12' 09"W
8	20° 23' 37"S	40° 12' 45"W
9	20° 23' 45"S	40° 13' 24"W
10	20° 23' 14"S	40° 13' 08"W

Species such as the hydroids require the collection of samples to provide a precise identification down to species level. The crinoid genus *Tropiometra* was recognized in many different color displays. It is important to highlight that the sea star *Narcissia trigonaria* (Figure 6) is a threatened species according to the Brazilian Ministry of Environment (BRASIL 2004).

Three fish species were observed:

i. a sand-perch, *Diplectrum sp*., a bottom-dwelling species, common over sand/muddy bottoms;
ii. the Southern Atlantic sharpnose-puffer, *Canthigaster figueiredoi*, a small-size species, endemic to Brazil that may reach up to 12cm in length;
iii. the Spanish hogfish, *Bodianus rufus*, a widespread species along the west Atlantic.

Table 3: Organisms identified in the video records.

Phylum	Subphylum	Class	Order	Family	Genus	Species
Cnidaria		Anthozoa	Alcyonacea	Ellisellidae	*Ellisella*	*Ellisella elongata* (Pallas, 1766)
Cnidaria		Anthozoa	Alcyonacea	Gorgoniidae	*Leptogorgia*	*Leptogorgia* cf. *punicea* (Milne Edwards & Haime, 1857)
Cnidaria		Anthozoa	Alcyonacea	Clavulariidae	*Carijoa*	*Carijoa* cf. *riisei* (Duchassaing & Michelotti, 1860)
Cnidaria		Hydrozoa	Leptothecata	Aglaopheniidae	*Macrorhynchia*	*Macrorhynchia* cf. *philippina* (Kirchenpauer, 1872)
Cnidaria		Hydrozoa	Leptothecata	Aglaopheniidae	*Aglaophenia*	*Aglaophenia* cf. *latirostris* (Nutting, 1900)
Echinodermata	Asterozoa	Asteroidea	Valvatida	Ophidiasteridae	*Narcissia*	*Narcissia trigonaria* (Sladen, 1889)
Echinodermata	Crinozoa	Crinoidea	Comatulida	Tropiometridae	*Tropiometra*	*Tropiometra cf. carinata* (Lamarck, 1816)
Chordata	Tunicata	Ascidiacea	Aplousobranchia	Didemnidae	*Didemnum*	*Didemnum* spp.
Chordata	Vertebrata	Actinopterygii	Perciformes	Serranidae	*Diplectrum*	*Diplectrum* sp.
Chordata	Vertebrata	Actinopterygii	Perciformes	Labridae	*Bodianus*	*Bodianus rufus* (Linnaeus, 1758)
Chordata	Vertebrata	Actinopterygii	Tetraodontiformes	Tetraodontidae	*Canthigaster*	*Canthigaster figueiredoi* (Moura & Castro, 2002)

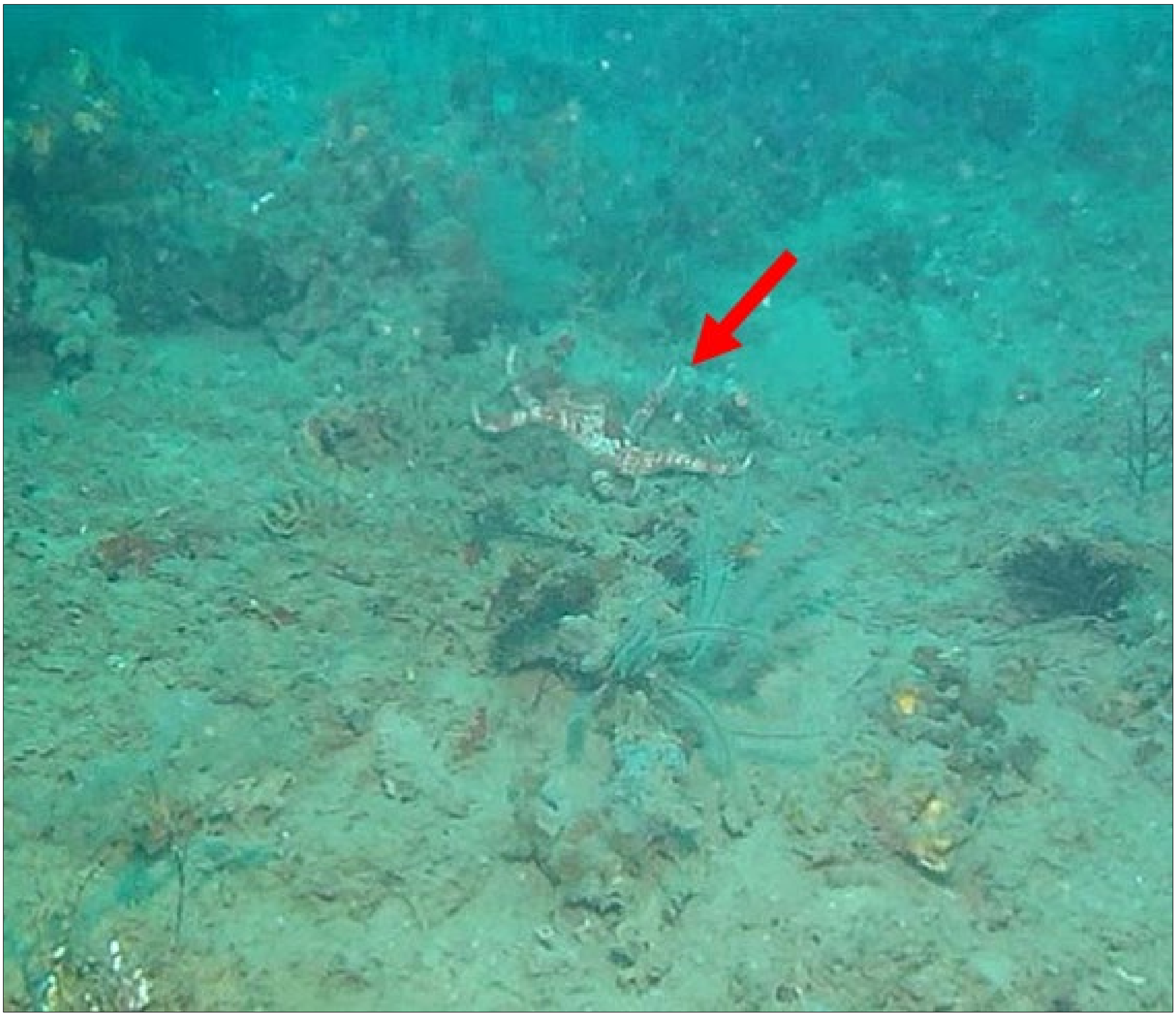


Figure 6: Seastar *Narcissia trigonaria*, a threatened species (observed at diving spot number 1 – see Table 3 for more information).

Notably, these fish species are typical of reef areas, suggesting that these areas present shallower relief structures that work as shelter for these species.

In terms of substrate type, most of the species were related to muddy sands, biogenic concretions, and hard muds. Almost all species from the Echinodermata and Cnidaria phyla identified were observed over hard mud – except *Leptogorgia* cf. *punicea* (Milne Edwards & Haime 1857) and *Macrorhynchia* cf. *philippina* (Kirchenpauer, 1872) from the Cnidaria phylum, which were also observed at soft mud.

From the Chordata phylum, species were found at muddy sands, sometimes combined to bioclastic material, while the *Didemnum spp.* and *Diplectrum sp.* were also observed in soft mud bottoms (mixed with sands). Table 4 presents the relation between species and types of substrates.

5. Discussions

The great presence of mud (sometimes combined with sands) on the study area suggests the influence of surrounding disposal of dredge material, as dredging activities are constantly being undertaken over the harbor complex and estuary of Vitória, and the shallow continental shelf is an area of interest for the dumping of the referred mud material. Junior *et al.* (2009) and Moscon & Bastos (2010) described the presence of muddy sands and muds in Vitória's bay when they characterized the estuarine seabed morphology and its sediment composition.

Moscon & Bastos (2010) evaluated the composition and geometry of sediment deposits of the Espírito Santo bay throughout a side scan sonar survey and sediment samples analysis. They observed that sediment grains' diameter ranges from coarse to very fine sands, muddy sands, marls, and very fine muddy silicibioclastic sands. The authors' study related lower acoustic reflection of the side scan sonar's pattern to very fine muddy siliciclastic sands, and higher reflection was associated with coarse to very coarse siliciclastic sands. Also, they identified bedform patterns composed mainly by muddy fine sand, concentrated over the northeastern region of Espírito Santo bay (depths of -5 to -8m). Following the sonograph register's interpretation of Moscon & Bastos (2010), the present study also revealed the correlation between the higher acoustic reflection of the signal to the presence of sand deposits. However, we associated this pattern to sands combined to hard mud substrate. Yet, low acoustic reflection was interpreted likewise as muddy sands deposits, and specifically, in this study case, it was further related to soft muds.

Table 4: Substrate type and number of appearances *vs* Species found.

Phylum	Species	Substrate type	Diving spot
Cnidaria	*Ellisella elongata* (Pallas, 1766)	Consolidated (muddy sands mixed with bioclastic material)	5
Cnidaria	*Leptogorgia* cf. *punicea* (Milne Edwards & Haime, 1857)	Consolidated (hard mud; muddy sands mixed with bioclastic material; muddy sands); Unconsolidated (hard mixed with soft mud)	1; 3; 5; 10
Cnidaria	*Carijoa* cf. *riisei* (Duchassaing & Michelotti, 1860)	Consolidated (hard mud; muddy sands mixed with bioclastic material);	3; 5; 6
Cnidaria	*Macrorhynchia* cf. *Philippina* (Kirchenpauer, 1872)	Consolidated (hard mud; muddy sands mixed with bioclastic material); Unconsolidated (hard mixed with soft mud)	1; 3; 5; 6
Cnidaria	*Aglaophenia* cf. *Latirostris* (Nutting, 1900)	Consolidated (hard mud; muddy sands mixed with bioclastic material)	1;5
Echinodermata	*Narcissia trigonaria* (Sladen, 1889)	Consolidated (hard mud)	1
Echinodermata	*Tropiometra* cf. *carinata* (Lamarck, 1816)	Consolidated (muddy sands mixed with bioclastic material)	5; 6
Chordata	*Didemnum spp.*	Consolidated (hard mud; muddy sands mixed with bioclastic material); Unconsolidated (soft mud)	1; 2; 3; 5; 6; 7
Chordata	*Diplectrum sp.*	Unconsolidated (soft mud mixed with sand); Consolidated (muddy sands)	3; 10
Chordata	*Bodianus rufus* (Linnaeus, 1758)	Consolidated (muddy sands)	10
Chordata	*Canthigaster figueiredoi* (Moura & Castro, 2002)	Consolidated (muddy sands)	10

Vieira (2017) mapped types of reef structures on the Espírito Santo continental shelf, based on its geometry and spatial distribution and seabed morphology. The author cited the presence of isolated reefs, bioconstructions associated with paleochannels, and concretions, in depths between -15 and -45m. These records corroborate the data presented here, showing depths from -33 to -43m, and including the presence of calcareous concretions. Vieira (2017) identified hardbottom structures on the edges and inside the paleochannels, throughout sonograms visualization. The structures were interpreted as bioconstructions (i.e., calcareous concretions, as seen at the Jucu river paleochannel border).

Considering that the studied area was mainly characterized by the presence of consolidated sediments (ca. 73.5%), it's important to emphasize that hard bottoms shelves under low sedimentary input provide conditions for the establishment of biogenic structures (Moura *et al.* 2016). The distribution of the living organisms converged to diving points numbers 1, 3, and 5 (situated in east and northeast regions of the surveyed area), where it was registered at least 9 species. At the same time, those appearances were related to smooth elevations of ca. 0.5m high.

It has been proved that geophysical methods represent an extremely efficient tool for preliminary ecological evaluation of dredge disposal sites (Wienberg *et al.* 2004, Bellec *et al.* 2010, Miller *et al.* 2016, Madricardo *et al.* 2019, Ternes *et al.* 2019). For this reason, the relationship between bottom recognition through subaquatic filming and the characterization by interpreting the acoustic signal reflection of seabed composition was a key aspect for the relevancy of this environmental assessment and thus could support decisions on designating sites for the disposal dredge material from harbors. Although it's a scarce methodology in Brazil, the mapping of Geohabitats (the combination of geological, hydrodynamic, and biological characterization of the seafloor) is essential to ensure the preservation of benthic community among coastal regions related to economic activities such as ports and harbors (Ternes *et al.* 2019).

6. Conclusions

The present paper provides information about seabed morphology and benthic ecology of the inner continental shelf on a potential area for the dumping of dredged material from Vitória's harbor (Espírito Santo, Brazil). It highlights the efficiency of acoustic geophysical measurements together with *in situ* observations for evaluating disposal sites and the monitoring of those areas.

The bathymetric survey revealed a relatively plain and homogenous bottom surface, varying between -33m and -43m depth. The deepest zones are connected to the paleochannel of Jucu's river, part of the incised valleys known in the region. Calcareous biogenic concretions, identified through side scan sonar and underwater images, are related to shallower reliefs, with approximately 0.5m high, and show a scattered distribution over the bottom surface of the entire area. Benthic and nektonic organisms present a heterogenous distribution and the occurrence of a threatened species of starfish (*Narcissia trigonaria*) was detected.

The ecological diversity is strongly related to the geomorphology. The synergy among these elements is corroborated by the observation that the highest richness of benthic and nektonic species occurs in the shallowest zones and on consolidated bottoms, where biogenic structures were also established. The disposal of dredged material over those communities may cause their disappearance.

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