



Geohabitats characterization in areas of dredge sediment disposals on Rio de Janeiro continental shelf, adjacent to Guanabara Bay: Brazil

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Abstract

Disposal of dredged sediments from harbor areas is often carried out without prior characterization and diagnosis of the benthic ecosystem and its relationships with the physical environment. Geohabitats studies contribute to this previous characterization, showing how geological and geomorphological features are associated with the benthic ecosystems of a given location. To investigate these relationships, acoustic geophysical methods (echobotimetry, sonography, and high-resolution seismic) and direct observation methods (underwater video and geological sampling) were used in two distinct areas on the Rio de Janeiro continental shelf, adjacent to Guanabara Bay: Area I (degraded with dredging disposal) and Area II (control, without disposal). After the acquisition, processing, and integrated data interpretation, it was possible to determine 5 (five) classes of geohabitats: class I, areas with high acoustic reflectivity, with little or any presence of benthic organisms, under the direct influence of discarded material; class II, areas of high acoustic reflectivity, with predominance of quartzose sand mixed with calcareous fragments (shells), with abundance and diversity of benthic organisms; class III, areas of very high acoustic reflectivity (backscattering), with high abundance and diversity of benthic organisms, indicative of semi-consolidated seafloor (articulated algal “reefs”); class IV, areas with high acoustic backscattering, with strong presence of bed forms (megaripples), associated with the quartzose sand; and class V, areas of low acoustic reflectivity, with sand-muddy textures, low abundance, and relative diversity of benthic organisms. It was verified that the use of these noninvasive GEOHAB techniques had an excellent correlation between the obtained results and proved to be an important tool for the characterization of Geohabitats in areas of dredge sediment disposals on Rio de Janeiro continental shelf, adjacent to Guanabara Bay—Brazil.

Keywords Geohabitats · Environmental management · Dredging · Disposal · Rio de Janeiro continental shelf

Introduction

Shallow-shelf marine areas are the most affected by human activities that have been altering and affecting the environmental quality of these regions. Dredge sediment disposal and several industrial and domestic pollutants are dumped daily worldwide in bays, estuaries, and inner shelf (Kjerfve

et al. 2001; Baptista Neto et al. 2006). In particular the dredged sediments disposed in open sea sites, called oceanic disposal areas, commonly known as “bota-fora” in Brazil (Pereira 2013), strongly affect the water quality, sediment pollution, and benthic fauna and flora (Lee et al. 2010; Marmin et al. 2014).

The use of geophysical methods to characterize discards from dredging sediments in Brazil is still little explored, even though these are pointed out internationally as a good tool for evaluation and dredge monitoring disposal sites (Valente 2004; Lepland et al. 2009).

In the Rio de Janeiro continental shelf, a number of “dredging discards” have been carried out without previous characterization and diagnosis of the benthic ecosystem and its relations with the physical environment. Therefore, the environmental impact of those human activities cannot be quantified,

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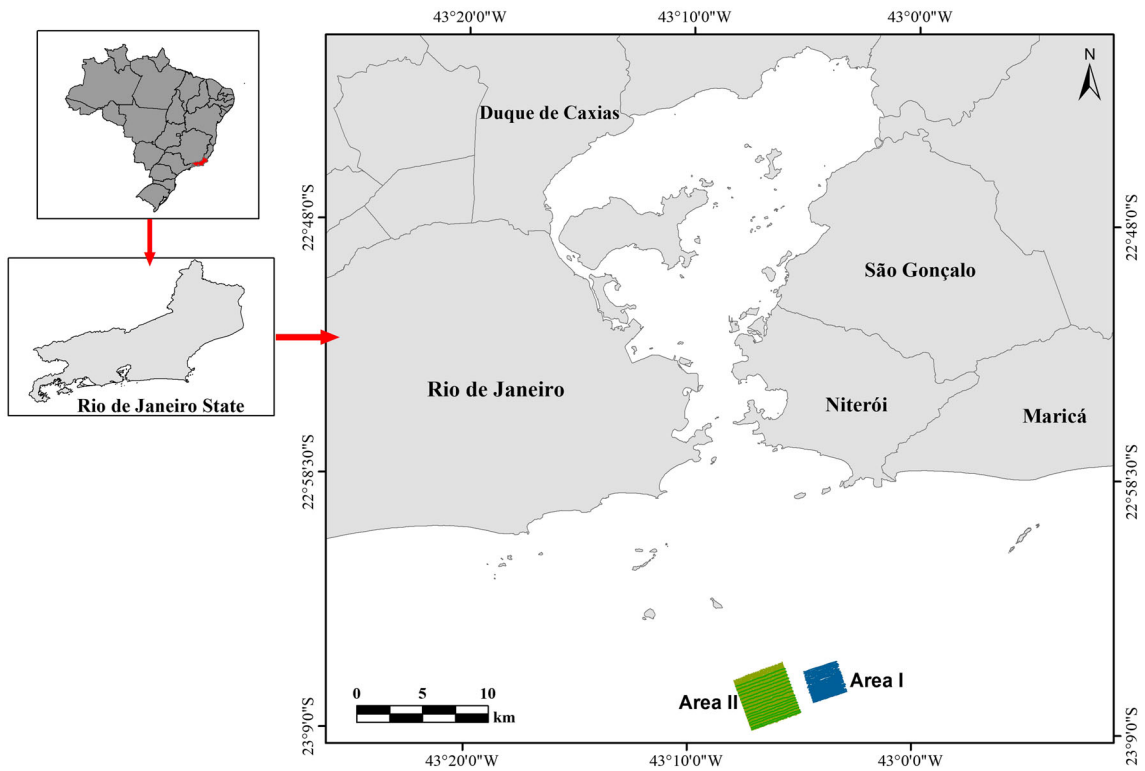


Fig. 1 Location of the study areas, delimited by the 2 polygons, Area I (blue) and Area II (green)

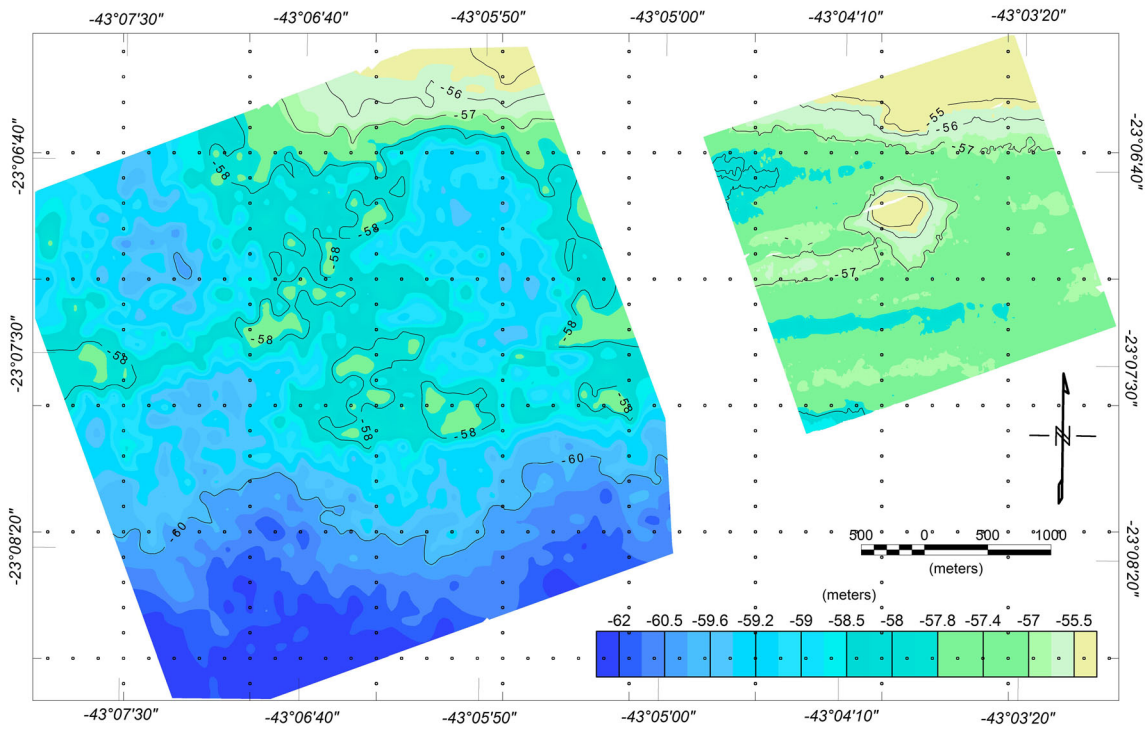


Fig. 2 Bathymetric map of the study areas: Area I (right) and Area II (left), showing their main morphological characteristics

since there is no way to compare the pre- and post-intervention situations. For this reason, it is necessary to map marine habitats, a priori, to provide inputs for decision-makers on coastal management. Studies of living and nonliving natural resources are ecologically important for these areas. In this aspect, maps of Geohabitats, generated through the integration of geological, geophysical and biological data, can indicate how such geomorphological features are associated with the benthic ecosystems of a given location. From the applied point of view, the prior mapping of Geohabitats (i.e., geological, hydrodynamic, and biological characterization of the seafloor) is internationally recognized as an important tool for supporting the management of these coastal environments (Haep and Harris 2011; Moura et al. 2013; Lamarche et al. 2016; McGrath 2016).

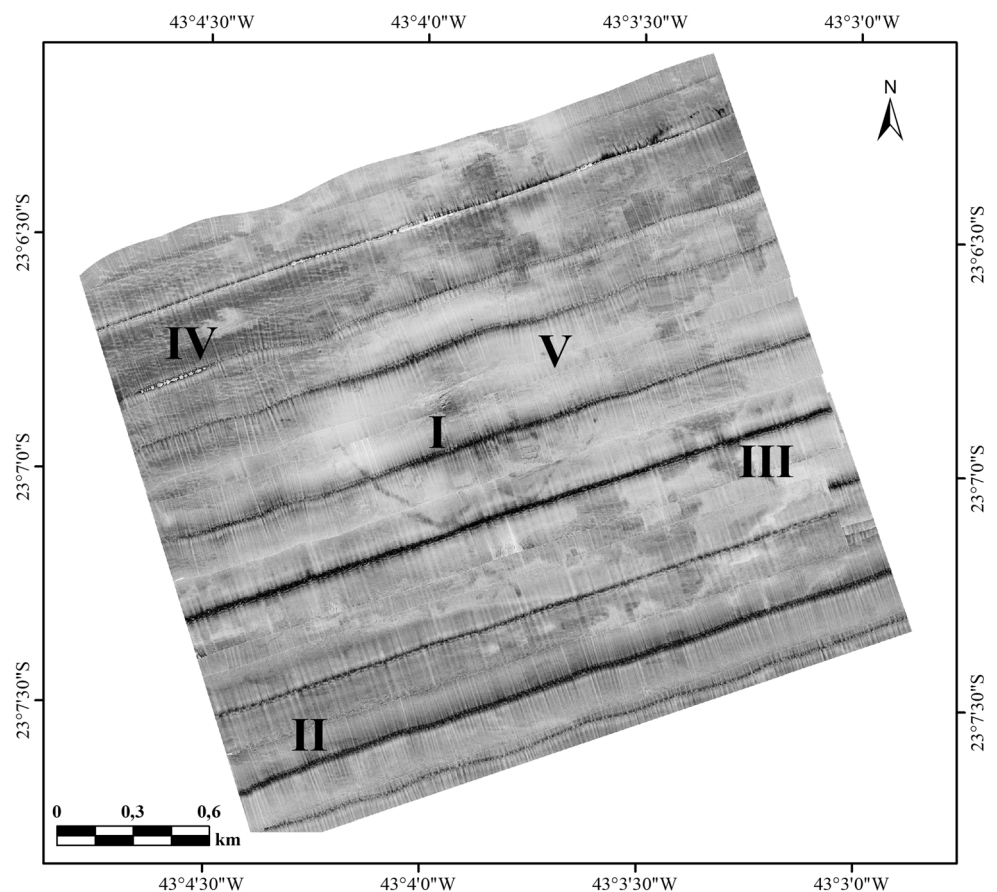
In this perspective, benthic habitats are defined in terms of seabed characteristics, such as morphology and sediment texture, which can be detected and mapped with high-resolution using modern geophysical techniques. This approach strongly emphasizes the concept of benthic habitat as “habitation” or “preferred substrate” for benthic organisms, despite of

individual species or whole communities. Thus, the characterization of the physical structure of the seabed, through acoustic surveys techniques, is the basis for the mapping of benthic habitats and its appropriate biological interpretation (Kostylev et al. 2001; Diaz et al. 2004; Tyrrell 2004; Lund and Wilbur 2007; Tood and Kostylev 2011).

However, a habitat is, in fact, something that encompasses more than substrate or structure. Habitat mapping methods are not universal and must respect the objectives, area of coverage, and scale of maps to be generated. This initial characterization is essential for determining the cover of the associated fauna and flora (Kostylev et al. 2001; Diaz et al. 2004). So far, these techniques provide a set of fundamental information for the selection of appropriate sites and subsequent environmental licensing that disposal areas and/or exclusion areas for preservation (Harris and Baker 2011; Figueiredo et al. 2015).

In Brazil, studies of Geohabitats are scarce and, when they exist, are not necessarily associated with the planning and execution of dredging discard projects. In general, the efforts are focused on a general mapping to give support to the delimitation of conservation areas, such as the Abrolhos

Fig. 3 Sonographic mosaics for Area I with the location of sonographic standards (Roman numbers) are described in Table 1



National Park (Secchin 2011; Moura et al. 2013) or mapping the benthic marine habitats of local character (Oliveira and Dominguez 2016).

In order to investigate those Geohabitats' relationships, acoustic geophysical methods (echobotimetry, sonography, and high-resolution seismic) and direct observation methods (underwater video and geological sampling) were used in two distinct areas on the Rio de Janeiro continental shelf, adjacent to the Guanabara Bay (Fig. 1). These areas were denominated Area I (a degraded with dredging sediments disposal area) and Area II (a control area, without any disposal). Therefore, the main objective of this work is to characterize and compare two distinct areas of dredged sediment dumped, from Rio de Janeiro Harbor, for an environmental impact assessment in the benthic ecosystem, based on the GEOHAB methodologies

Materials and methods

In these two areas investigated, we have executed 8 field surveys for the acquisition of geophysical data, video imaging,

and sediment sampling between September 2015 and April 2016. Geological and geophysical surveys were carried out by the Department of Geology of the Fluminense Federal University (Lagemar/UFF), and underwater images were provided by Mr. Otto Sobral, from the Fishermen's Colony Z-7, in Niterói (RJ) and Prof. Gilberto Dias (UFF). During the surveys, the sensors positioning were performed with a NOVATEL DGPS positioning system, with differential corrections provided by satellite, obtaining sub-metric precision. For the vessel navigation, the software HYPACK 2013 was used.

The bathymetric data in Area I was obtained with an OHMEX SonarMite single-beam system operating in 200 kHz. In Area II, the bathymetry was performed using a RESON 7101 multibeam system. Both data were post-processed in the Caris HIPS software. To measure the sound velocity in the water column for calibrating the echo sounders, a sound velocity profiler Odom Digibar Pro was used.

In the sonographic study, a digital side-scan sonar system EdgeTech 4100P with a 272TD towfish (100/500 kHz) was used in both areas. After acquisition, the sonar images were processed in the SonarWiz 5 software from Chesapeake.

Fig. 4 Sonographic mosaics for Area II with the location of sonographic standards (Roman numbers) are described in Table 1

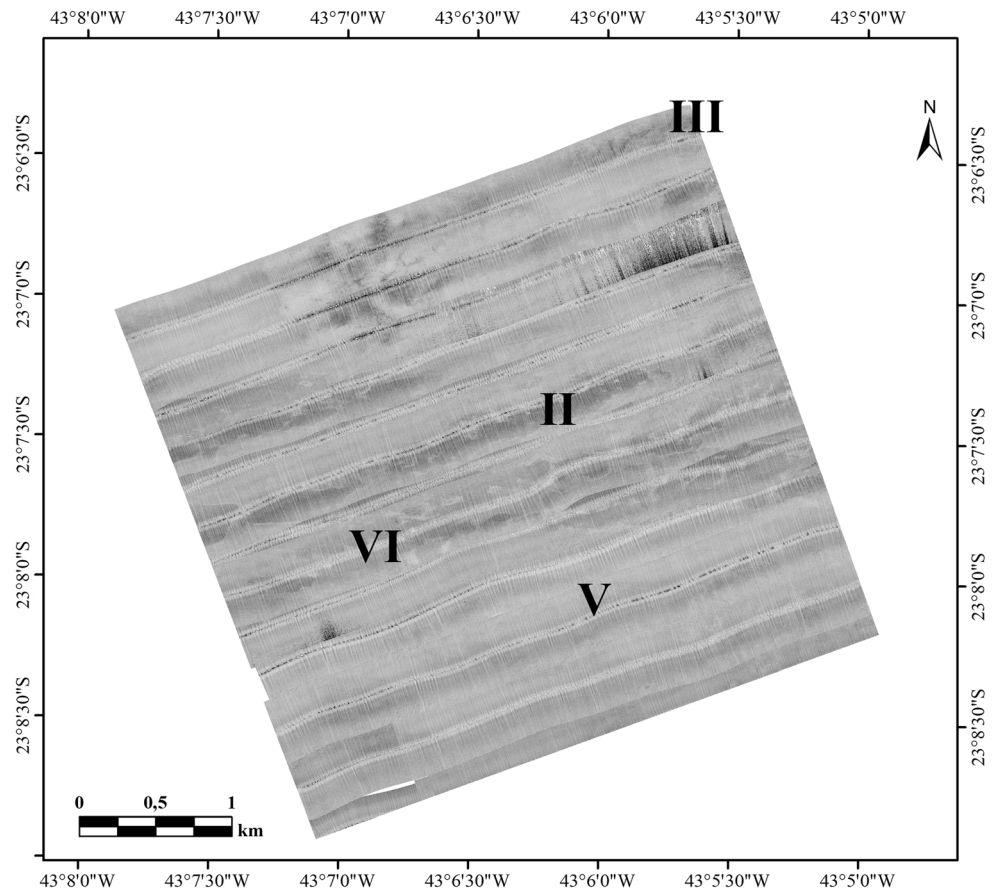
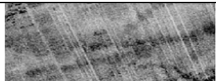
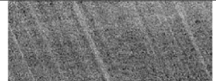
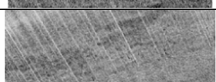
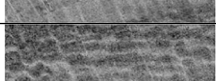

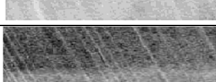


Table I Sonographic patterns observed in Areas I and II

Pattern	Acoustic reflectivity	Bottom Texture	Interpretation	Example
I	Very high	Heterogeneous	Dredging Disposal areas	
II	High	Heterogeneous	Quartzose sand with calcareous fragments (shells)	
III	High to Intermediate	Heterogeneous and irregular	Indicative of semi consolidated bottom	
IV	Intermediate	Heterogeneous	Quartzose sand with bed forms (megaripples)	
V	Low	Homogenous	Muddy sand	
VI	Intermediate to low	Heterogeneous	Intercalations of sand with calcareous fragments (shells) and muddy sand	



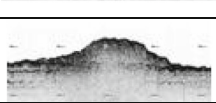

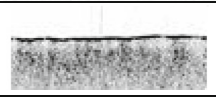
The equipment used in the seismic surveys was a 5100/560P multifrequency profiling system (CHIRP) from EdgeTech Inc. with a 2–16 kHz towfish (SB216S). The acquired data was processed in the Triton 3D Perspective software.

After the integrated interpretation of acoustic data (bathymetric, seismic, and sonographic), we have selected

28 sites, in strategic areas, for ground truthing. In these sites, submarine video imaging and sediment bottom samples were carried out where textural variations were found in the geoacoustic images (seismic and sonographic) processed.

Two drop cameras were used (camera 1, MCH 300 with 530 lines of resolution and Sony Exview CCD, and

Table II Seismic patterns observed in Areas I and II

Pattern	Acoustic reflectivity	Bottom	Interpretation	Example
I	Very high	Heterogeneous	Quartzose sands with calcareous fragments (shells)	
II	High	Heterogeneous and irregular (serrated with continuity)	Indicative of “semi consolidated seafloor” (calcareous algal “reefs”)	
III	High	Heterogeneous and irregular	Disposal of dredged material	
IV	Low	Homogeneous	Muddy sand	
V	Intermediate to low	Heterogeneous	Fine surface sediments (silt and clay) over thicker sediment layer (Quartzose sand)	

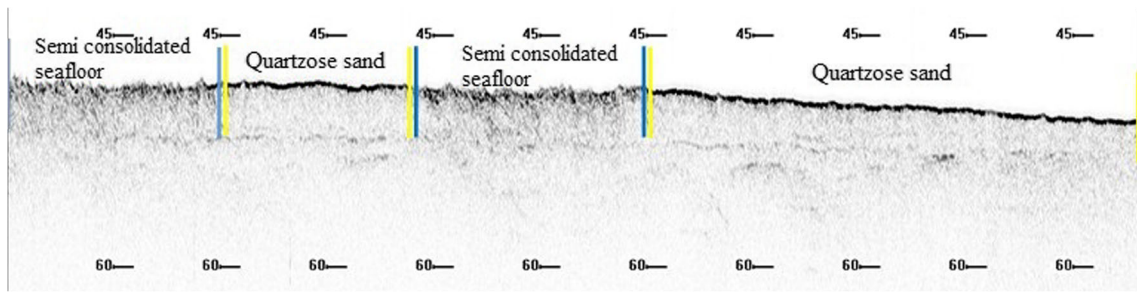


Fig. 5 Example of semi-consolidated seafloor observed in seismic lines

Camera 2, GoPro 1080P resolution). They were mounted with a light diffuser in a stainless steel frame, with approximately 40 cm of height. This structure has a keel in the rear, allowing to record always in a frontal way, toward the drifting of the boat.

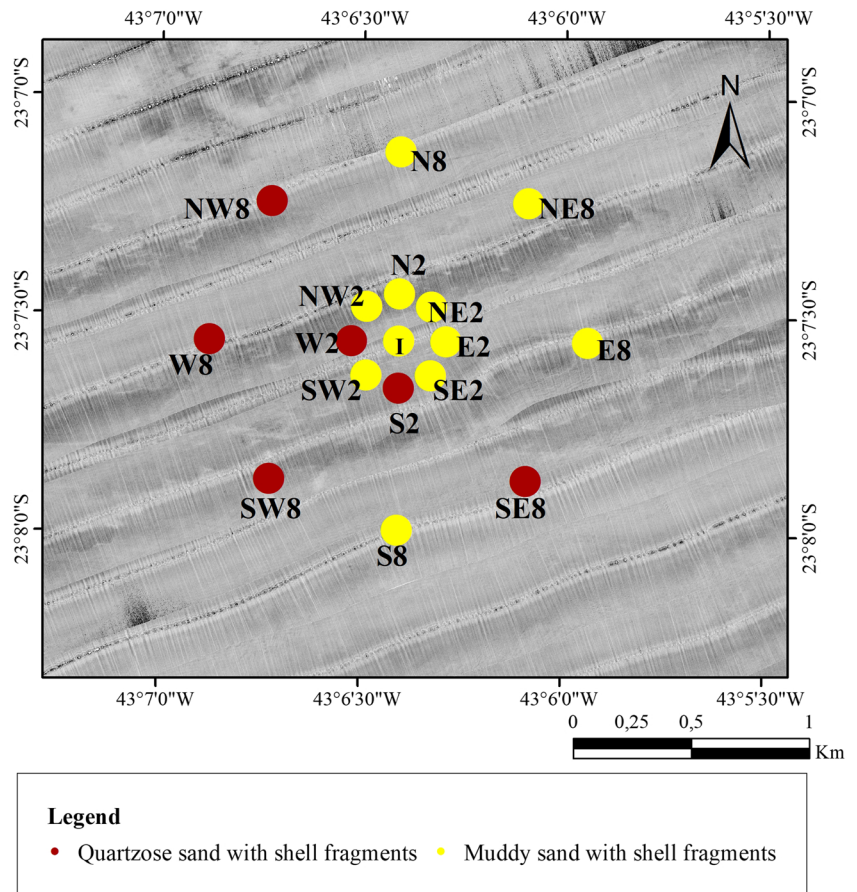
The 17th bottom sediment samples were taken in Area II with a 15-liter Van Veen sampler and were photographed macroscopically described and packaged on board.

Results

Bathymetry

The depths in Area I range from -43.5 to -55.5 m while in Area II range from -56 m (north) to -62 m (south) (Fig. 2). The Area I, submitted to dumping of dredged material, presents the bottom morphology quite irregular. Two predominant disposal

Fig. 6 Sonographic mosaic (zoom) of Area II (right) and II (left) and the location of the sample points



sites, with distinct geomorphologic characteristics, can be observed: one to the north, smaller, and another, larger, in the center of the area, called “Central Discard” (presenting the lowest depths of this area, -43.5 m). Linear morphological features in the SW-S portion of Area I differ from the rest of this area, showing the greatest depths of Area I. The lowest depth values of Area II were found in the N-NE portion, in the form of a high bathymetric (terrace) with E-W orientation. Note that this lineament has continuity from Area II to Area I (Fig. 2).

Sonography

By analyzing the sonographic mosaics (Figs. 3 and 4), echotexture variations of the sea bottom, it was possible to identify 6 (six) different types of sonographic patterns, described in Table I. In the N-NW portion of Area II, dark spots are observed, possibly cavities generated by dolphins in searching of food. It is noteworthy that in the vicinity of these features, during the sonographic survey, a group of dolphins (*Stenella frontalis*) were observed moving. Their “noise” recorded in the sonograms indicates that this region may be a feeding point for these animals (Dias et al. 2016).

The Sonographic Pattern I present the highest backscatter, related to dredged sediment discard, occurring only in Area I. In the central deposition area, a circular pattern with dark tones is observed, following the navigation path around the center point. It was also observed, in the upper part of Area I (northeast), another local with high acoustic reflectivity, related to a second discard area of smaller dimensions than the “Central Discard.”

The Sonographic Pattern II, highly reflective and heterogeneous, is associated with the presence of quartzose sand and calcareous fragments (shells); being observed mainly near the outer limits (NE, NW, SE, SW) of Area I and in the central portion of Area II.

The Sonographic Pattern III, heterogeneous and irregular, was previously described as being indicative of “semi-consolidated bottom.” Subsequently, observing the videos, a hypothesis was raised relating this type of reflection to the presence of articulated calcareous algae “reefs.” Due to the fact that it is an “impacted area” (Area I) with dredged material dumping, these features were covered by sediments from the discards. Therefore, they were better identified in the seismic profiles (Seismic Pattern II in Table II). According to verbal

Table III Textural and granulometric classification in samples of Area II. QSSF = quartzose sand with shell fragments and MSSF = muddy sand with shell fragments

Sample	Granule > = 2 mm (%)	Very coarse sand 2–1 mm (%)	Coarse sand 1–0.5 mm (%)	Medium sand 0.5–0.25 mm (%)	Fine sand 0.25–0.125 mm (%)	Very fine sand 0.125–0.0625 mm (%)	Silt 0,0625–0,0039 mm (%)	Clay 0.0039–0,00195 mm (%)	Classification
I	3.7	6.4	8.5	18.3	22.1	27.8	6.7	6.4	MSSF
N8	0.9	2.0	2.9	3.6	15.9	51.2	12.6	10.9	MSSF
NE8	0.4	3.4	7.3	8.7	17.0	45.0	8.3	9.9	MSSF
E8	1.3	3.3	5.0	10.7	27.2	41.0	7.8	3.7	MSSF
SE8	4.2	7.8	13.9	19.9	19.0	26.1	7.9	1.1	QSSF
S8	3.2	5.6	8.6	14.7	15.4	37.4	10.2	4.9	MSSF
SW8	4.7	12.8	27.6	19.3	10.4	17.1	5.4	2.7	QSSF
W8	4.2	6.3	7.9	13.4	22.1	36.7	7.2	2.3	QSSF
NW8	2.9	6.0	11.4	15.0	17.7	37.3	6.9	2.8	QSSF
N2	3.3	7.7	12.4	14.5	23.9	28.6	8.4	1.3	MSSF
NE2	3.7	6.9	15.2	18.4	9.4	21.8	11.8	12.8	MSSF
E2	2.8	8.6	22.9	12.3	14.8	15.4	2.6	20.5	MSSF
SE2	0.7	2.9	4.9	14.9	26.0	40.3	5.6	4.7	MSSF
S2	2.3	9.3	20.9	24.9	15.0	20.5	5.7	1.3	QSSF
SW2	3.9	8.4	13.0	13.8	14.1	33.9	10.3	2.5	MSSF
W2	4.7	9.1	18.0	21.9	8.8	28.3	66	2.6	QSSF
NW2	3.7	9.0	12.9	12.2	12.7	30.8	16.0	3.0	MSSF

information from fishermen, these areas were often used as fishing grounds before the dredge sediment disposals.

The Sonographic Pattern IV, of intermediate and heterogeneous reflectivity, was observed in the northwest (NW) portion of Area I and in the northeast (NE) portion from the central discard point, where the sea bottom still preserves natural characteristics evidenced by the bed forms (megaripples). This sonographic pattern was not observed in Area II, probably due to the composition of the bottom sediments, with a higher amount of fine sediments (silt and clay).

The Sonographic Pattern VI was observed only in the central portion of Area II, related to morphological lineaments in this region.

High-resolution seismic

It was possible to identify 5 (five) seismic patterns associated to different material compositions (Table II). In

both areas, it was possible to map 3 (three) seismic reflectors (horizons) from the seafloor to the acoustic basement. Any outcrop of the crystalline basement was observed in the analyzed seismic lines.

Area I presents interplay between seismic patterns I and IV, being predominantly composed by quartzose sand associations with calcareous fragments (shells) and large regions with predominance of muddy sand. The Seismic Pattern III was found only in Area I, because it is the pattern related to the discharge of dredged sediment material. The Seismic Pattern V was found only in Area II.

The Seismic Pattern II, indicative of “semi-consolidated seafloor” (Fig. 5), was observed in the SW portion of Area I at a depth of -53 m. It is related to carbonate concretions related to calcareous articulated algae “reefs,” but any bottom samples were recovered from these locations.

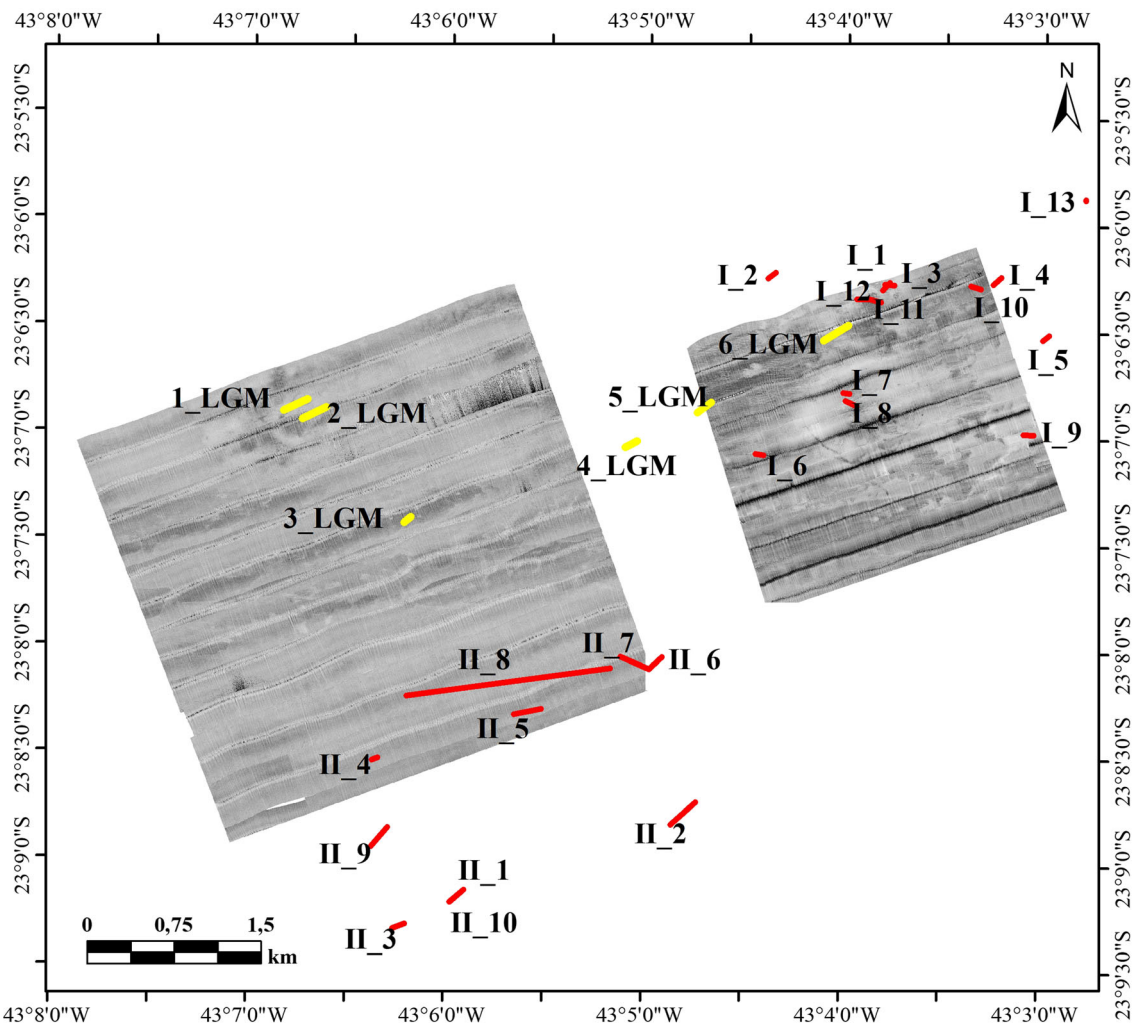


Fig. 7 Sonographic mosaics of Areas I (right) and II (left) and the location of the shooting points. Lines in yellow color were performed by the Lagemar/UFF team. Lines in red represent the route of filming performed by the fisherman Otto Sobral

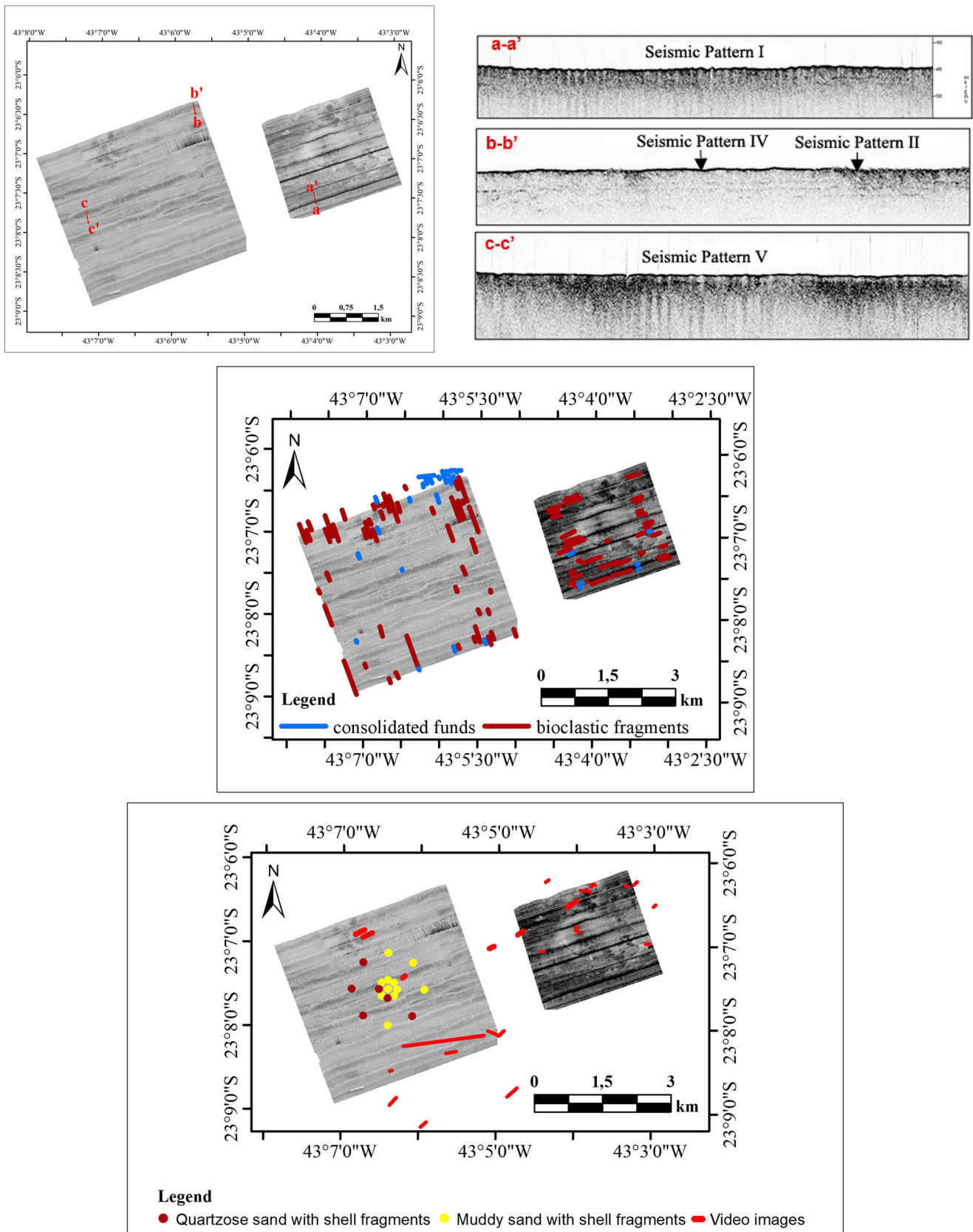


Fig. 8 Example of integration of various data. (a) Sonographic mosaic on the left, with the geographical position of examples of seismic lines (a-a'; b-b'; c-c') and their respective seismic patterns (right). (b) Example of

result of the integration of the seismic patterns I and II with the sonographic mosaics. (c) Data of geological samples and position of the videos for parameterization of the proposed seabed classes

Samplings and bottom videos

The sediment samples collected in the central portion of area II (Fig. 6) presented medium to dark brown coloration. The grain analysis revealed a greater fraction of fine sand and coarse sand with gravels (fragments of shells). The textural classification ranged from “quartzose sand with shell fragments” and “muddy sand with shell fragments.” The results of the particle size analysis reveal that the seabed is quite homogeneous, with a predominantly sandy matrix and variations in the amount of gravel and fine fractions (silt and clay) (Table III). These results are in accordance with studies of Dias (2004), where the predominance of sandy sediments on the continental shelf of Rio de Janeiro was described.

The sites for video imaging and sediment samples (Fig. 7) were selected according to the patterns described above from the sonograms and high reflection seismic records. It is worth mentioning that some shooting points are located in regions surrounding the investigated areas. However, these points were essential for the understanding and characterization of the study areas.

The NE-E portion and the surroundings of Area I received special attention in the characterization of the videos, due to reports by the fishing community (Colony Z7), to be a region used as a fishing area. These sites present sandy bottom with bioclastic fragments, great presence of benthic organisms, and several associated fish. The greatest diversity of benthic organisms in Area I is associated with semi-consolidated bottoms and sandy bottoms with bioclastic (shell fragments) and whole shells, articulated calcareous algae. The filming showed a fish characteristic of rocky or semi-consolidated bottoms (Michole, *Diplectrum* sp.).

The dredged material discard locations (in Area I only) show compacted deposits of mud agglutination blocks, sediment mixtures, rock fragments, and plastic fragments. At the upper discard point (north), a sandy matrix with large presence of mud (compacted or not) is observed. All the filming locations of Area I present, in common, the resuspension of fine material, revealed at the moment of the camera frame touching the bottom.

Based on the images of Area II, it was observed that the surrounding areas present a mixing between sandy bottoms and low amounts of bioclastic fragments, with starfishes and

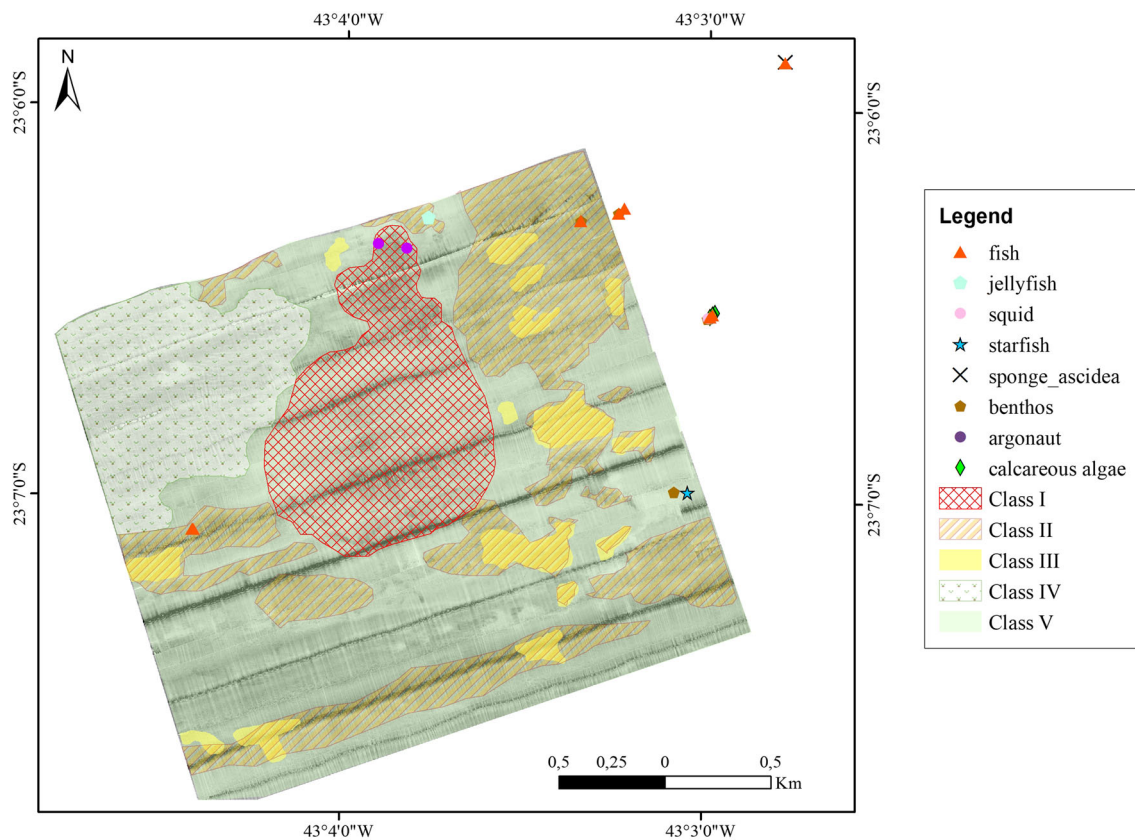


Fig. 9 Classes of Geohabitats and associated organisms observed through videos—Area I

polychaetes. Bioclastic fragments are composed mostly of shell fragments.

The S-SE portion of Area II shows a larger amount of bioclastic fragments (whole shells) and a large amount of benthic fauna and flora (articulated calcareous algae), jellyfish, and even an argonaut shell. In the sonographic mosaic, they correspond to Sonographic Pattern II (Table I). A large number of ophiuroids were visualized only in the northern portion of Area II, close to the sonographic and seismic patterns of higher reflectivity, with strong evidence of semi-consolidated bottoms. These are possible feeding sites of dolphins, as previously mentioned.

The presence of bottom elevation (Terrace) at NE, as well as lineaments located at the SW portion, is observed by analyzing the two areas together (Fig. 2). Both features appear to have continuity between the two areas (I and II), as presented both in the sonographic mosaics and in the seismic profiles, with high values of acoustic backscattering. The variation in the concentration of bioclastic fragments (shell fragments) and the presence of whole shells, visualized in the filming, show a correlation with the high reflectivity pattern observed in sonographic mosaics and seismic profiles and are related to the greater abundance and diversity of benthic organisms.

Determining Geohabitats classes

The integrated interpretation of the geological and geophysical data collected with different methods (echobotimetry, sonography, high-resolution seismic, geological samples, and seabed filming) allowed the determination of 5 (five) classes of Geohabitats in the study area. Figure 8 exemplifies this integration, in which the sonographic and seismic data interpreted revealed acoustic reflectivity (echotexture) patterns for each of these methods. The use of high-resolution seismic provides support for understanding the surface layer mapped by side-scan sonar, as already suggested by Lund and Wilbur (2007).

After this interpretation (Fig. 8A), the geoacoustic patterns were integrated into georeferenced maps (GIS) for the characterization of the marine substrate (Geohabitats). Figure 8(B) shows the seismic patterns I and II together with the sonographic mosaics for both areas. It is observed that the higher intensities of acoustic backscattering both in sonography and in the shallow seismic are compatible. Those are represented by sonographic patterns II and III and seismic patterns I and II. All of them correspond to the quartzose sand with bioclastic fragments and to the indicative patterns of consolidated funds, respectively.

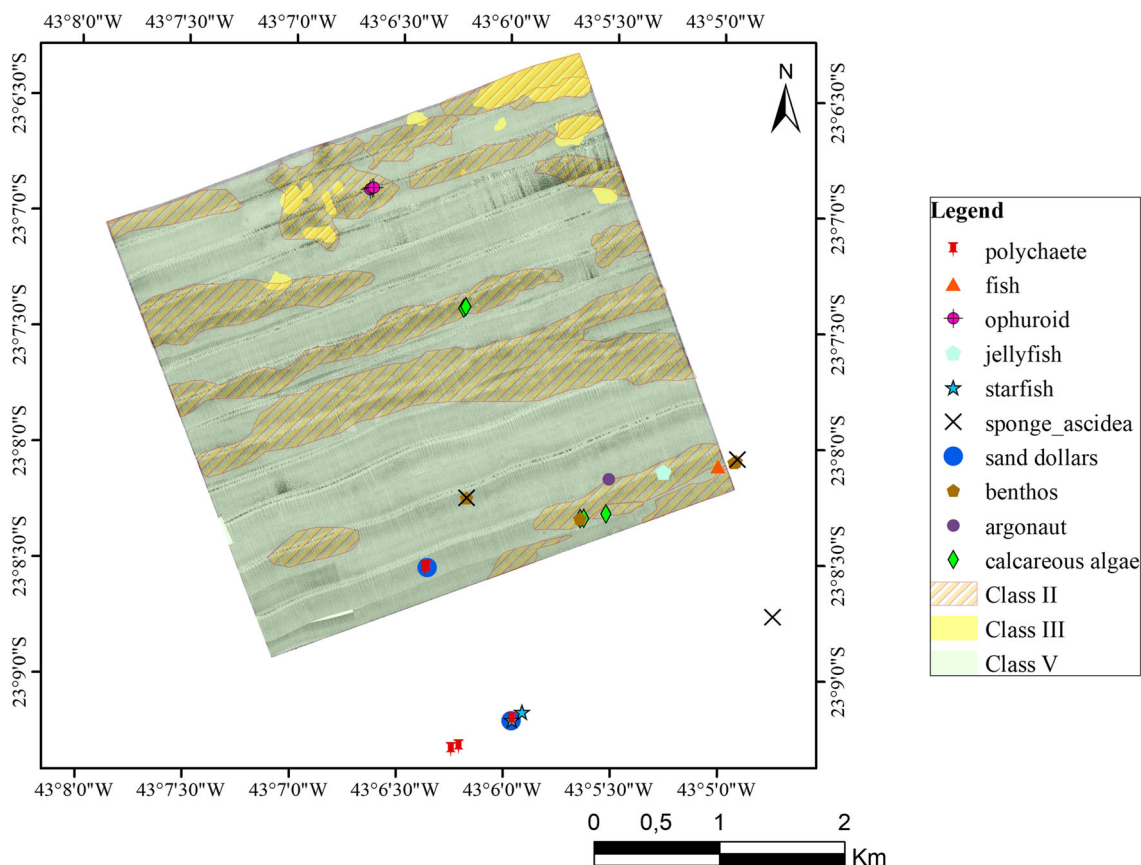


Fig. 10 Classes of Geohabitats and associated organisms observed through videos—Area II

These initial classes of the marine substrate were properly parameterized with the available data of geological sampling and filming (Fig. 8C) for the definition of the Geohabitats classes.

After all these integration and analysis, it was possible to compile a map of benthic habitats (Figs. 9, 10), with those 5 (five) classes, as follows:

- Class I—areas with high acoustic reflectivity, with little or any presence of benthic organisms, under the direct influence of discarded material
- Class II—areas with high acoustic reflectivity, with predominance of quartzose sand with bioclastic fragments and shells, presenting abundance and diversity of benthic organisms
- Class III—areas of very high acoustic reflectivity, with high abundance and diversity of benthic organisms, indicative of semi-consolidated bottom

- Class IV—areas with high acoustic reflectivity, with strong presence of bed forms (megaripples) in the bottom, associated with quartzose sand
- Class V—areas of low acoustic reflectivity, with muddy sand textures, low abundance and relative diversity of benthic organisms

Benthic organisms have few distribution differences between the two areas. Polychaetes are found only in areas associated with Class V (muddy sand bottoms) of Area II, as well as the “sand dollar” echinoid found at these sites. It should be noted that sites with Class II (quartzose sand with bioclastic fragments and shells) or Class III (indicative of rough bottom) showed greater abundance and diversity of associated benthic organisms. The presence of articulated calcareous algae was observed only in filming at sites with these seabed characteristics.

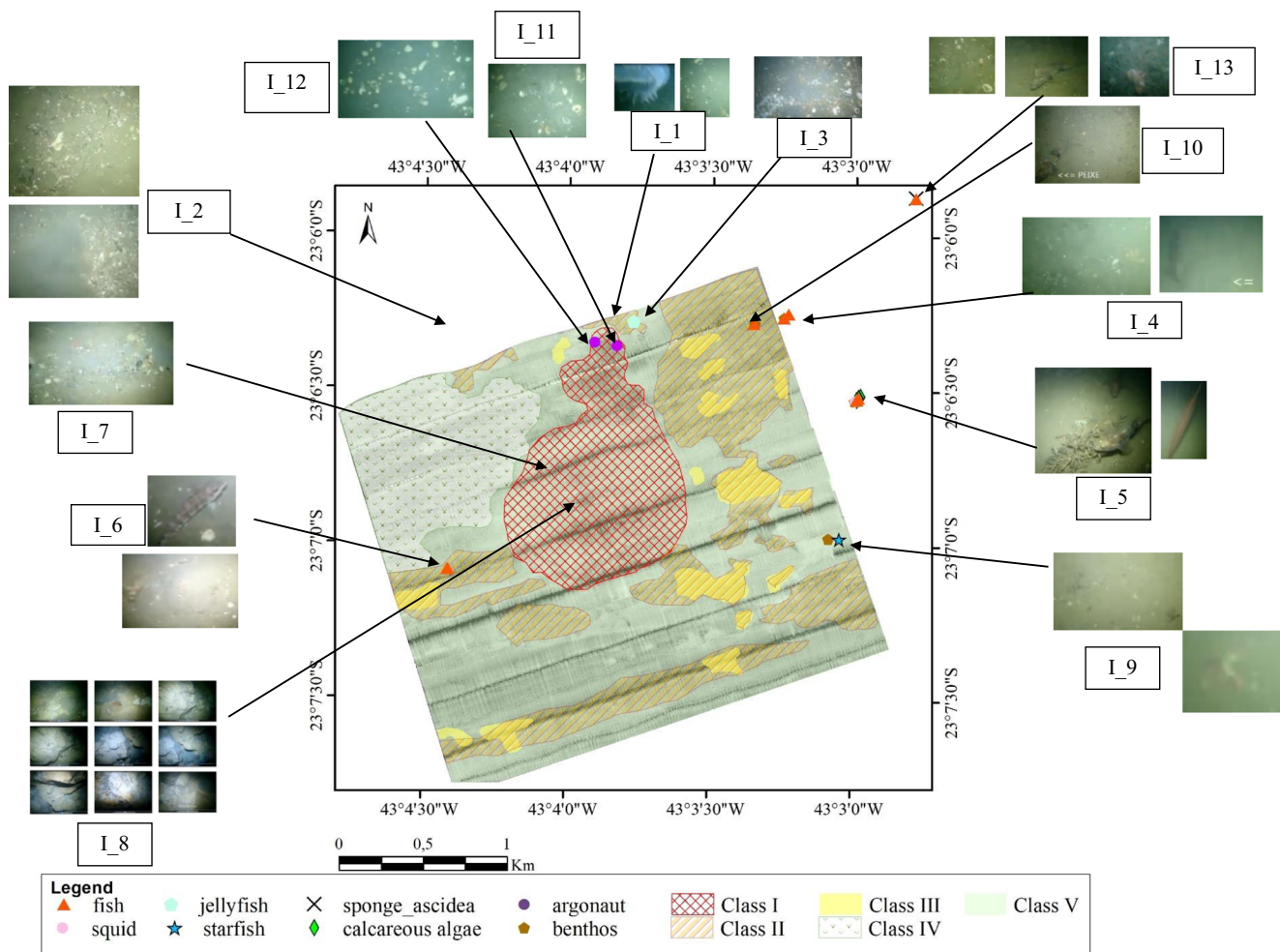


Fig. 11 Map of Geohabitats classes for Area I, with the visualization of images of seabed sediments and benthic organisms observed at each point of filming

In the area that receives the discards of dredged material (Class I), mainly in the Central Discard point of Area I, the presence of benthic organisms is not observed. The composition characteristics of the dredged material showed a strongly compacted appearance, which would explain the permanence of the material in place, with little dispersion by bottom currents. Figure 7 shows the 5 classes of Geohabitats and the observed positions of each benthic organism visualized in the videos.

Geohabitats classes can be viewed separately, for each area in Figs. 11 and 13 (Area I and II), and Figs. 12 and 14 are a zoom for more details in both areas. In these figures, representative images of the sea bottom characteristics and benthic organisms, visualized in each section, were associated to each shotpoint, proving a very good correlation among all the data (Fig. 13). In addition, it can be confirmed that the filming is a reliable source for geoaoustic data parameterization together with the geological samplings. Figure 9, in particular, represents the Geohabitats classes defined for Area I. The difference in gray scale at the dredged disposal sediment site (Class I)

in contrast to the rest of the area is clearly seen. Figure 14 (Area II) reveals a greater amount of articulated calcareous algae, always associated to classes that present greater acoustic reflectivity (Classes II and III). It is observed that in Area I, the presence of these algae was only observed in this environment.

The use of underwater video imaging filming and sediment sampling, associated to the described geoaoustic methods, greatly contributed to the characterization of the areas, providing the parameterization of benthic habitats. For example, sonographic and seismic patterns of higher acoustic reflectivity are related to sites indicative of the presence of “semi-consolidated seabed” (articulated calcareous Algae) or quartzose sand with large number of bioclastic fragments and shells. In these places, articulated calcareous algae were visualized in the filming, being often associated to different species of fish (*Diplectrum* sp. and *Dules auriga*) and other fishes of difficult identification. These regions are located in the outer limits of NE or around Area I.

The dredged material disposal points (Area I) presented high acoustic reflectivity of the sedimentary material

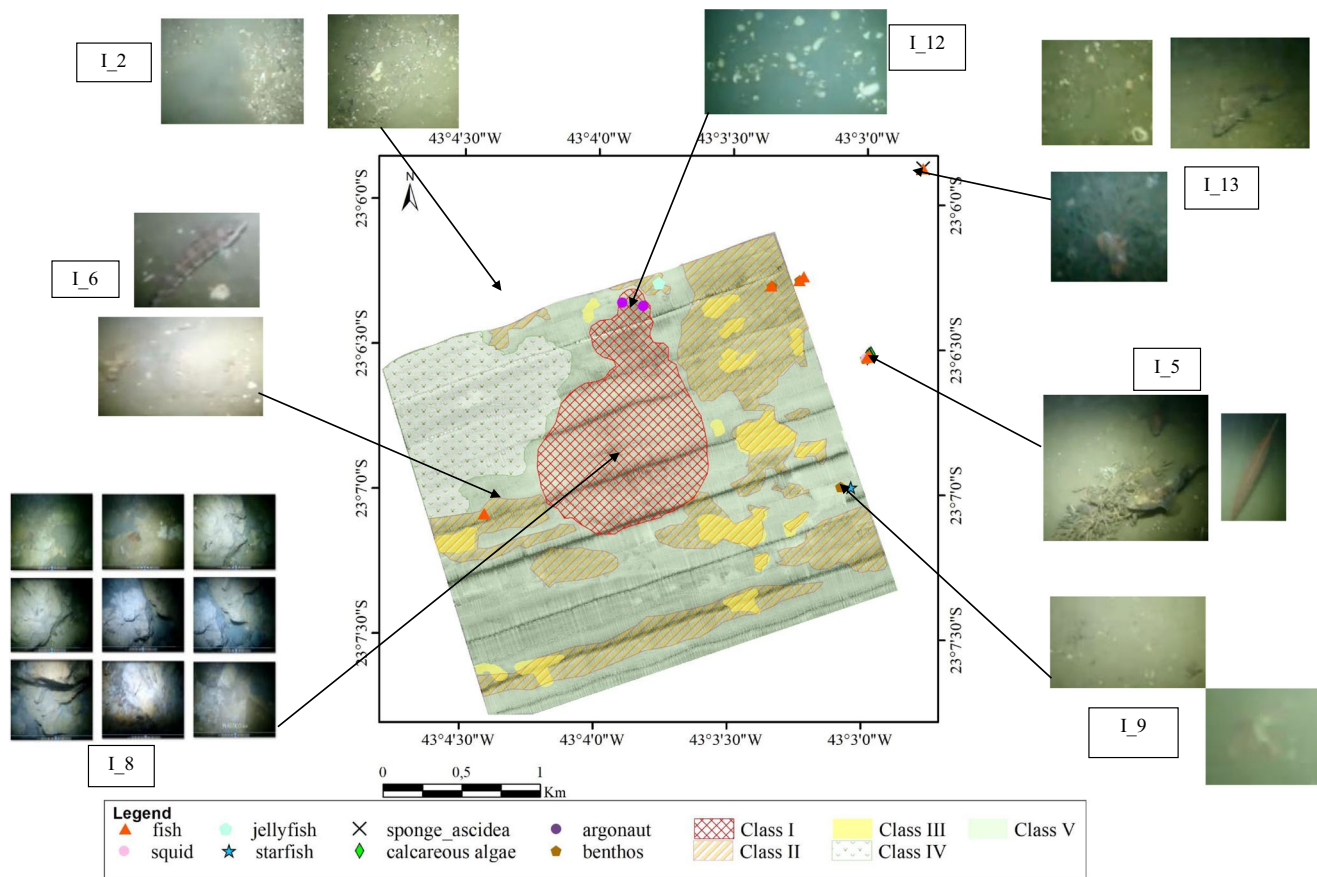


Fig. 12 Map of Geohabitats classes for Area I, with the visualization of marine sediment images and benthic organisms observed at each point of filming. Zoom in the areas with different classes for more details

(compacted mud) accumulated in the seabed. At these points, benthic organisms were not visualized in the submarine video images. In general, sites with low acoustic reflectivity characteristics, both in sonography and seismic, were associated with muddy sand bottom sandy-loamy backgrounds, with abundance of polychaetes and sometimes echinoderms (“sand dollar” and starfish). These variations of echofacies are compatible with video frames filming and geoacoustic data, including the lateral relationship of the submarine bottom between sonographic and seismic patterns found in Areas I and II-

Conclusions and recommendations

The use of integrated geoacoustic methods (echobatimetry, sonography, and shallow high-resolution seismic), underwater video imaging, and sediment sampling greatly contributes to the characterization of the studied areas, providing the parameterization of its benthic habitats. The sonographic and seismic patterns of higher acoustic reflectivity are related to sites indicative of the presence of “semi-consolidated seabed” (articulated calcareous algae) or quartzose sand with large number of bioclastic fragments and shells, associated to different

species of fish (*Diplectrum* sp. and *Dules auriga*) and other fishes of difficult identification.

The dredged sediment materials at the disposal points (Area I) presented high acoustic reflectivity associated with a compacted mud seabed. At these points, benthic organisms were not visualized in the submarine video images. In general, sites with low acoustic reflectivity characteristics, both in sonography and seismic, were associated with muddy sand bottom, with abundance of polychaetes and sometimes echinoderms (“sand dollar” and starfish). These variations of echofacies are compatible with the video frames and geoacoustic data, including the lateral relationship between sonographic and seismic patterns found in Areas I and II.

After all those data processing, integration, and analysis, it was possible to establish 5 (five) classes of Geohabitats, as follows:

- Class I—areas with high acoustic reflectivity, with little or any presence of benthic organisms, under the direct influence of discarded material
- Class II—areas with high acoustic reflectivity, with predominance of quartzose sand with bioclastic fragments

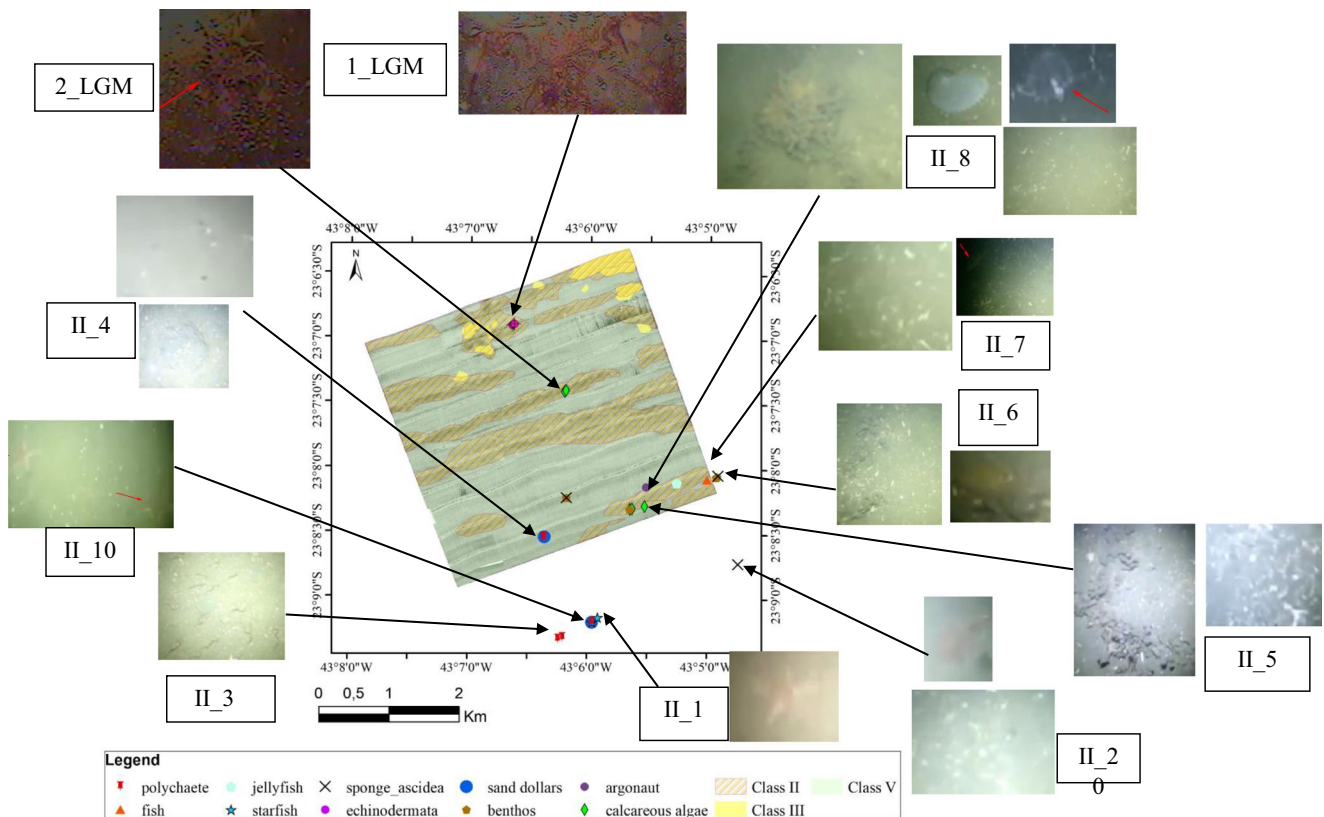


Fig. 13 Map of Geohabitats classes for Area II, with the visualization of marine sediment images and benthic organisms observed at each point of filming

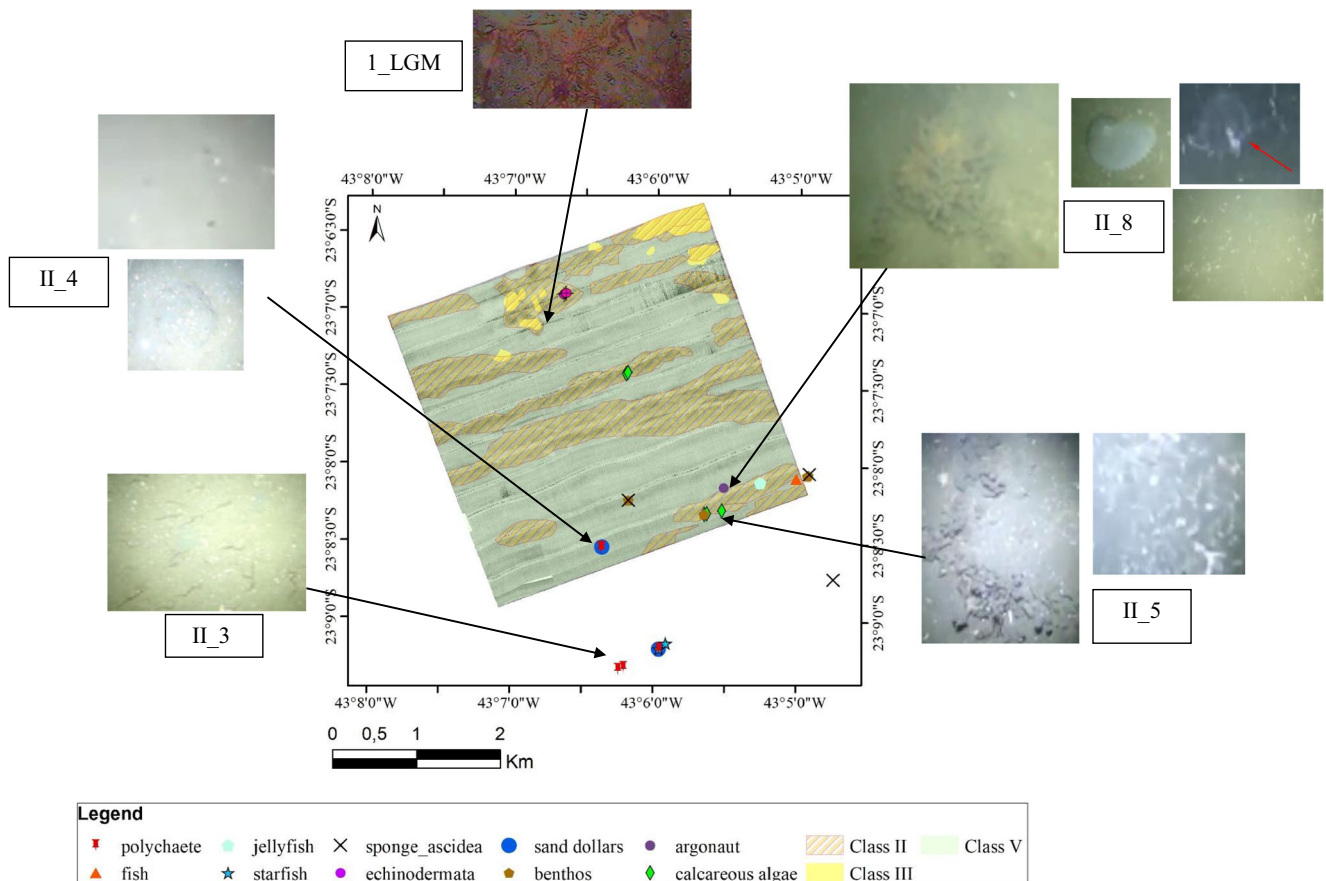


Fig. 14 Map of Geohabitats classes for Area II, with the visualization of marine sediment images and benthic organisms observed at each point of filming. Zoom in the areas with different classes for more details

and shells; presenting abundance and diversity of benthic organisms

- Class III—areas of very high acoustic reflectivity, with high abundance and diversity of benthic organisms, indicative of semi-consolidated bottom
- Class IV—areas with high acoustic reflectivity, with strong presence of bed forms (megaripples) in the bottom, associated with quartzose sand
- Class V—areas of low acoustic reflectivity, with muddy sand textures, low abundance and relative diversity of benthic organisms

It is concluded, therefore, that the studies of Geohabitats constitute an essential tool for prior environmental characterization of areas to be used as discarded dredged sediment sites from harbors.

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References

Baptista Neto JA, Brehme I, Gingele FX, Leipe T (2006) Spatial distribution of heavy metals in surficial sediments from Guanabara Bay: Rio de Janeiro, Brazil. *Environ Geol* 49:1051–1063

Dias GTM (2004) Carta de sedimentos marinhos superficiais-Plataforma Continental e Talude superior. In: *Cartas Sedimentológicas de Fundo da Plataforma Continental Brasileira*. UFF/Lagemar

Dias GTM, Fontelles C, Silva RCO, Silva CG, Lima LS, Fonseca EM (2016) “Geohabitat mapping in the continental shelf off Guanabara Bay, Rio de Janeiro, Brazil”. ECSA 56. 4-7 September 2016. Bremen. Germany.

Diaz RJ, Solan M, Valente RM (2004) A review of approaches for classifying benthic habitats and evaluating habitat quality. *J Environ Manag* 73:165–181

Figueiredo Jr. AG, Pacheco CEP, Vasconcelos SC, Silva FT (2015) “Geomorfologia e Sedimentologia da Plataforma Continental”. Kowmann, R.O. (org.) In: *Caracterização Ambiental Regional da Bacia de Campos, Atlântico Sudoeste*. Geologia e Geomorfologia. Série Habitats. Vol.1 Rio de Janeiro-RJ. Ed. Elsevier. p. 13-32.

Haep AD, Harris PT (2011) Geological and biological mapping and characterisation of benthic marine environments—Introduction to the special issue. *Cont Shelf Res* 31(2):S1–S3. <https://doi.org/10.1016/j.csr.2010.09.015>

Harris PT, Baker EK (2011) “Why map benthic habitats?” Harris PT; Baker EK (Org.) In: *seafloor geomorphology as benthic habitat*.

- GeoHab Atlas of seafloor geomorphic features and benthic habitats. Ed. Elsevier. p.3-26.
- Kjerfve B, Lacerda LD, Dias GTM (2001) Baía de Guanabara, Rio de Janeiro, Brazil. In: Coastal marine ecosystems of Latin America. Org. Kjerfve B, Seeliger U Springer. Volume 144 the series Ecological Studies. p.107-117.
- Kostylev VE, Todd BJ, Fader GBJ, Courtney RC, Cameron GDM, Pickrill RA (2001) Benthic habitat mapping on the Scotian Shelf based on multibeam bathymetry, surficial geology and sea floor photographs. *Mar Ecol Prog Ser* 219:121–137
- Lamarche G, Laferriere A, Gardner J, Geange S, Pallentin A, Zintzen Z, Curtis H (2016) “Making the New Zealand Kapiti marine reserve an integrative part of its natural and societal environment through habitat mapping”. Abstract Booklet Geohab 2016. Marine Environment Mapping and Interpretation – from the Coast to the Deep Ocean: p128
- Lee DI, Eoma KH, Kim GY, Baeck GW (2010) Scoping the effective marine environmental assessment of dredging and ocean disposal of coastal sediments in Korea. *Mar Policy* 34:1082–1092
- Lepland A, Bøe R, Lepland A, Totland O, (2009) “Monitoring the volume and lateral spread of disposed sediments by acoustic methods, Oslo Harbor, Norway”. *Journal of Environmental Management*. 90: 3589–3598.
- Lund K, Wilbur AR (2007) “Habitat classification feasibility study for coastal and marine environments in Massachusetts”. Massachusetts Office of Coastal Zone Management. Boston, MA. 31p. <http://www.mass.gov/eea/docs/czm/habitat/ma-habitat-classification-study.pdf> Access: 02/11/2016.
- Marmin S, Dauvin JC, Lesueur P (2014) Collaborative approach for the management of harbour-dredged sediment in the Bay of Seine (France). *Ocean Coast Manag* 102:328–339
- McGrath F (2016) “MeshAtlantic - Mapping Atlantic Area seabed habitats for better marine management”. Abstract Booklet Geohab 2016. Marine Environment Mapping and Interpretation – from the Coast to the Deep Ocean. p131.
- Moura RL, Secchin NA, Amado-Filho GM, Francini-Filho RB, Freitas MO, Minte-Vera CV, Teixeira JB, Thompson FL, Dutra GF, Sumida PYG, Güth AZ, Lopes RM, Bastos AC (2013) Spatial patterns of benthic megahabitats and conservation planning in the Abrolhos Bank. *Cont Shelf Res* 70:109–117
- Oliveira RG, Dominguez JML (2016) “Mapeamento de habitats marinhos bentônicos da porção nordeste da Baía de Todos os Santos – Bahia – Brasil”. VII Congresso Brasileiro de Oceanografia. Salvador – Bahia. Painel.
- Pereira TG (2013) Abordagem multimetodológica sobre o despejo de sedimentos de dragagem em área de descarte oceânico - plataforma adjacente à Baía de Guanabara. Universidade Federal Fluminense. Tese (Doutorado em Dinâmica dos Oceanos e da Terra), Niterói 282 p
- Secchin NA (2011) Mapeamento de habitats marinhos na plataforma dos Abrolhos. Dissertação de Mestrado. Universidade Federal do Espírito Santo. 72p.
- Tood BJ, Kostylev VE (2011) Surficial geology and benthic habitat of the German Bank seabed, Scotian Shelf, Canada. *Cont Shelf Res* 31: 54–68
- Tyrrell MC (2004) Strategic plan for mapping Massachusetts’ benthic marine habitats. Massachusetts Office of Coastal Zone Management, Boston <http://www.mass.gov/eea/docs/czm/habitat/strategic-mapping-plan.pdf>. Access: 01/11/2016.
- Valente RM (2004) The role of seafloor characterization and benthic habitat mapping in dredged material management: a review. *J Mar Environ Eng* 7:185–215

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