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MAPEAMENTO DE HABITATS MARINHOS EPIBENTÔNICOS DA PORÇÃO NORDESTE DA BAÍA DE TODOS OS SANTOS – BAHIA – BRASIL

RENATO GUIMARÃES DE OLIVEIRA

Salvador

2017

MAPEAMENTO DE HABITATS MARINHOS EPIBENTÔNICOS DA PORÇÃO NORDESTE DA BAÍA DE TODOS OS SANTOS – BAHIA – BRASIL

Renato Guimarães de Oliveira

Orientador: Prof. Dr. José Maria Landim Dominguez

Co-orientadora: Profª Dra. Carla Maria Menegola da Silva

Dissertação de mestrado apresentada ao Programa de Pós-Graduação em Geologia do Instituto de Geociências da Universidade Federal da Bahia como parte dos requisitos necessários para obtenção do título Mestre em Geologia, Área de Concentração: Geologia Marinha Costeira e Sedimentar.

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RENATO GUIMARÃES DE OLIVEIRA

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Dissertação apresentada ao Programa de Pós-Graduação em Geologia da Universidade Federal da Bahia, como requisito parcial para a obtenção do Grau de Mestre em Geologia na área de concentração em Geologia Marinha, Costeira e Sedimentar em 16/05/2017.

DISSERTAÇÃO APROVADA PELA BANCA EXAMINADORA:

____

José Maria Landim Dominguez – Orientador
Doutor em Geologia e Geofísica Marinha pela *Rosenstiel School of Marine and Atmospheric Sciences* da Universidade de Miami
Universidade Federal da Bahia

____

Tereza Cristina Medeiros de Araújo
Doutora em Geofísica pela *Universitat Kiel (Christian-Albrechts)*
Universidade Federal de Pernambuco

____

Helenice Vital
Doutora em Geologia e Geofísica Marinha pela *Christian Albrechts Universitat Zu Kiel*, Alemanha
Universidade Federal do Rio Grande do Norte

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RESUMO

O conhecimento das comunidades bentônicas marinhas é de fundamental importância ecológica e econômica. A abordagem tradicional dos estudos bentônicos envolve principalmente a coleta de organismos para triagem e identificação. Entretanto, este procedimento é extremamente demorado e dispendioso. O desenvolvimento de técnicas de sensoriamento remoto (ópticos e acústicos) minimizou significativamente este problema, possibilitando a geração de mapas espacialmente contínuos e de forma mais rápida. A área de estudo compreende a porção nordeste da BTS, localizada entre a ilha de Maré e a ilha dos Frades, próxima a grandes indústrias que contribuíram ou contribuem para acelerada degradação da região. O objetivo geral deste trabalho foi mapear os habitats marinhos epibentônicos da porção nordeste da BTS. Imagens de satélite de alta resolução disponíveis no Google Earth Pro foram usadas para delimitação de regiões opticamente distintas do leito marinho e regiões intermareais. A integração destas imagens a dados pretéritos disponíveis para área de estudo, permitiu a individualização das classes de substratos submarinos/costeiros a partir das quais foram selecionadas 145 estações amostrais para análise do epibentos. Nas zonas infralitorais, os trabalhos de campo consistiram de mergulho autônomo ou uso de drop câmera; e nas zonas intermareais o procedimento amostral ocorreu através de caminhadas ou utilizando pequenas embarcações, para otimização do tempo. Em todas as estações foi utilizada como unidade amostral um quadrado de 0,25 x 0,25 m para tomada de fotografias do substrato, além da utilização de draga *van veen* para coleta de sedimentos em regiões de substrato inconsolidado. Foram encontradas diferentes classes de substratos submarinos/costeiros. As análises dos dados de epibentos evidenciaram a presença de comunidades biológicas estaticamente distintas, entre a maioria das classes de substrato delimitadas. Utilizando uma combinação de todos esses dados, nove habitats marinhos epibentônicos foram identificados e mapeados. A combinação do uso de imagens de satélite de alta resolução com imagens fotográficas submarinas provou ser uma técnica útil e eficaz na caracterização de habitats marinhos epibentônicos.

Palavras chave: Comunidades epibentônicas. Substrato. Sensoriamento remoto. *Ground-thruthing*.

ABSTRACT

Knowledge of marine benthic communities is fundamental ecologically and economically. The traditional approach of benthic studies involves, mainly, sampling of benthic organisms for sorting and identification. However, this procedure is extremely time-consuming and costly. The development of remote sensing techniques (optical and acoustic) significantly minimized this problem, allowing faster production of spatially continuous maps. The study area comprises the northeastern portion of the BTS, located between the Maré island and Frades island, close to major industries that have contributed to the accelerated degradation of the region. The general objective of this study was to map the epibenthonic marine habitats of the northeastern portion of the BTS. High resolution satellite images available on Google Earth Pro were used to delineate optically distinct regions of the seabed. The integration of these images to previous data available for the study area allowed the individualization of subsea / coastal substrate classes from which 145 sample stations were selected for epibenthic analysis. A 0.25 x 0.25 m square was used as the sampling unit for substrate photography, (SCUBA dive and dropcam in the infralittoral regions, and walking and use of small boats in the intertidal zones), as well as the use of a *van veen* dredge for sediment collection in unconsolidated substrate regions. Different classes of submarine/coastal substrates were found. The analyzes of the epibenthos data showed the presence of statically distinct biological communities, among most of the substrate classes delimited. Using a combination of all these data, nine epibenthonic marine habitats were identified and mapped. The combination of the use of high resolution satellite images with underwater photographic images proved to be a useful and efficient technique in the characterization of epibenthic marine habitats. Different classes of submarine / coastal substrates were found. The analysis of epibenthic data evidenced the presence of statically distinct biological communities, among most of the classes of substrate delimited. Using a combination of all these data, nine epibenthonic marine habitats were identified and mapped. The combination of the use of high resolution satellite images with underwater photography proved to be a useful and effective technique for the characterization of epibenthic marine habitats.

Keywords: Epibenthonic communities. Substrate. Remote sensing. Ground-truthing.

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CAPÍTULO 1
INTRODUÇÃO

1. INTRODUÇÃO

Habitats marinhos bentônicos são áreas fisicamente distintas do substrato oceânico associadas à ocorrência de espécies particulares. Os habitats bentônicos representam o ambiente natural em que um organismo ou comunidade vive (Harris e Baker, 2011) e podem ser definidos por um conjunto de fatores geológicos, como tipo de substrato e pelos parâmetros físico-químicos da água (Diaz et al., 2004).

Os primórdios da produção de mapas do fundo oceânico remontam ao século XIII, quando comerciantes começaram a confeccionar cartas destinadas à navegação no Mediterrâneo (Blake, 2004). Estudos geológicos e biológicos só tiveram início efetivamente no século XIX, com a utilização de dragas primitivas para coleta de sedimentos e organismos bentônicos (McIntyre e Elefteriou, 2005). Petersen (1918); Holme (1961, 1966); e Cabioch (1968, apud Brown et al. 2002) são exemplos de estudos clássicos para a compreensão da variabilidade e distribuição da fauna bentônica ao longo de extensas áreas geográficas.

Atualmente, existe uma associação internacional de cientistas marinhos (GeoHab: http://geohab.org/) que estimula pesquisas no âmbito do mapeamento de habitats marinhos bentônicos, utilizando diferentes indicadores biofísicos como proxies para comunidades biológicas e diversidade de espécies (Harris e Baker, 2011).

A utilização, unicamente, de técnicas de amostragem convencionais (dragas, testemunhos, vídeos, fotografias e redes de arrasto), possui limitações para a geração de representações biofísicas precisas de áreas muito extensas. Levantamentos de pequena escala utilizando apenas as técnicas clássicas são dispendiosos, necessitando de uma grande densidade de dados e cobertura espacial para definir com precisão a heterogeneidade de habitats. Portanto, a utilização isolada dos métodos clássicos é útil apenas no estudo de pequenas áreas (Brown et al., 2011; van Rein et al., 2011). O desenvolvimento de técnicas como a batimetria multi-feixe, sonar de varredura lateral e LIDAR, possibilitaram minimizar estas dificuldades, com a amostragem direta utilizada apenas para a obtenção da verdade de campo (*Ground-thruthing*).

O termo "Surrogates" é aplicado para designar variáveis abióticas facilmente mensuráveis, que podem ser mapeadas e que apresentam uma correspondência quantificável à ocorrência de comunidades e espécies bentônicas (Harris, 2011). Essas variáveis podem atuar como preditores de padrões de distribuição de habitats bentônicos em áreas ainda não exploradas ou com levantamento de dados biológicos insuficiente (Harris, 2011). As variáveis abióticas, cujas influências sobre a distribuição dos organismos bentônicos são melhores conhecidas, são: textura e composição de sedimento, temperatura, salinidade, concentração de oxigênio e disponibilidade de luz (Snelgrove, 1999; Kostylev e Hannah, 2007). A identificação e o mapeamento de habitats marinhos bentônicos utilizando "surrogates" permite a caracterização de habitats em amplas áreas (Post, 2008).

A crescente pressão antrópica sobre os ambientes marinhos costeiros tem resultado no aumento de poluentes, na alteração e destruição de habitats, na acidificação e aquecimento das águas, na sobrepesca e na introdução de espécies exóticas (Wells, 1999). Deste modo, a implementação de planos integrados de gerenciamento costeiro é fundamental. Entretanto a fragmentação da gestão, faz com que as pressões antropogênicas e os recursos marinhos sejam tratados isoladamente (Crowder et al., 2006). Uma abordagem mais integrada que considere a interação entre as pessoas, o ambiente e os impactos das atividades humanas no funcionamento dos ecossistemas e sua resiliência, faz-se necessária (Baker e Harris, 2011). O gerenciamento baseado em ecossistemas (da sigla em inglês EBM – Ecossystem-based Management) representa um importante alternativa por reconhecer a conectividade dos elementos que compõem um ecossistema em funcionamento. Neste contexto, análises como o DPSIR (*Drivers, Pressures, State, Impact and Response*) necessitam de mapas de habitats para a obtenção de indicadores que permitem descrever o estado do meio ambiente e prever impactos.

A baía de Todos os Santos (BTS) não possui até o momento, um mapa de habitats marinhos bentônicos. A maior parte dos estudos realizados na região abordaram outros aspectos como contaminação química, oceanografia física, geológica, pesca, produção pesqueira, dentre outros.

Apesar de constituir uma Área de Proteção Ambiental, (APA Baía de Todos os Santos) criada por meio do Decreto Estadual nº 7595 de 05 de junho de 1999, esta unidade de conservação ainda não dispõe de um plano de manejo, ferramenta de extrema importância para a gestão ambiental, visto que a implementação deste, é fundamental para elaboração de diagnósticos da BTS e construção de um Zoneamento Ecológico Econômico (Blinder, 2009). A confecção de mapas de habitats marinhos, constitui-se, portanto, em uma etapa imprescindível para viabilização deste processo.

1.1. OBJETIVOS

1.1.2. Objetivo Geral:

- Mapear os habitats marinhos epibentônicos da porção nordeste da BTS.

1.1.3. Objetivos específicos:

- Identificar os principais organismos que compõem a megafauna epibentônica (a nível de grandes grupos) da porção nordeste da BTS;
- Mapear os substratos marinhos da porção nordeste da BTS;
- Analisar associações existentes entre a comunidade epibentônica e as classes de habitats estabelecidas;

1.2. ORGANIZAÇÃO DA DISSERTAÇÃO

Esta dissertação está subdividida em três capítulos:

Capítulo 1 – é apresentada a contextualização do trabalho e os aspectos que motivaram o desenvolvimento do presente estudo;

Capítulo 2 – são apresentados os resultados sob a forma de um artigo científico intitulado “Mapeamento de habitats marinhos epibentônicos da porção nordeste da baía de Todos os Santos – Bahia – Brasil”, submetido à revista *Marine Pollution Bulletin* (Qualis A2). Neste artigo é apresentado como resultado principal, um mapa de habitats marinhos epibentônicos, confeccionado para a porção NE da baía de Todos os Santos.

Capítulo 3 – são apresentadas as principais conclusões do trabalho.

2. REFERÊNCIAS

Baker, E. K., e Harris, P. T., 2011. Habitat Mapping and Marine Management. In: Harris, P.T. e Baker, E. K. (Eds.), Seafloor Geomorphology as Benthic Habitat: GeoHab Atlas of Seafloor Geomorphic Features and Benthic Habitats, Elsevier, Amsterdam, 2011, p. 23 - 38.

Blake, J., 2004. The Sea Chart: The Illustrated History of Nautical Maps and Navigational Charts. Conway Maritime Press.

Blinder, D., 2009. Nota Técnica – DUC - Nº. 24/2009. Secretaria de meio ambiente – SEMA. Superintendência de Políticas Florestais, Conservação e Biodiversidade – SFC. Diretoria de Unidade de Conservação e Biodiversidade – DUC. Governo do Estado da Bahia.

Brown, C., Cooper, K., Meadows, W., Limpenny, D., Rees, H., 2002. Small-scale Mapping of Sea-bed Assemblages in the Eastern English Channel Using Sidescan Sonar and Remote Sampling Techniques. Estuarine Coastal and Shelf Science, 54, 263–278.

Brown, C. J., Smith, S. J., Lawton, P., e Anderson, J. T., 2011. Benthic habitat mapping: A review of progress towards improved understanding of the spatial ecology of the seafloor using acoustic techniques. Estuarine, Coastal and Shelf Science, 92(3), 502-520.

Crowder, L. B., Osherenko, G., Young, O. R., Airamé, S., Norse, E. A., Baron, N., Day, J. C., Douvere, F., Ehler, C. N., Halpern, B. S., Langdon, S. J., Mc Leod, K. L., Ogden, J. C., Peach, R. E., Rosenberg, A. A. e Wilson, J. A., 2006. Resolving mismatches in US ocean governance. Science-New York then Washington, v. 313, n. 5787, p. 617-618.

Diaz, R. J.; Solan, M. e Valente, R. M., 2004. A review of approaches for classifying benthic habitats and evaluating habitat quality. Journal of Environmental Management, 73: 165–181.

Harris, P. T., 2011. Surrogacy. In: Harris, P.T. e Baker, E. K. (Eds.), Seafloor Geomorphology as Benthic Habitat: GeoHab Atlas of Seafloor Geomorphic Features and Benthic Habitats, Elsevier, Amsterdam, 2011, p. 93 - 108.

Harris, P. T. e Baker, E. K., 2011. Why Map Benthic Habitats? In: Harris, P.T. e Baker, E. K. (Eds.), Seafloor Geomorphology as Benthic Habitat: GeoHab Atlas of Seafloor Geomorphic Features and Benthic Habitats, Elsevier, Amsterdam, 2011, p. 3 - 22.

Holme, N. A., 1961. The bottom fauna of the English Channel. Journal of the Marine Biological Association of the United Kingdom, 41, 397–461.

Holme, N. A., 1966. The bottom fauna of the English Channel. Part II. Journal of the Marine Biological Association of the United Kingdom, 46, 401–493.

Huff, L. C., 2008. Acoustic remote sensing as a tool for habitat mapping in Alaska waters. Marine Habitat Mapping Technology for Alaska, 10, 29-45.

Kostylev, V.E., Hannah, C.G., 2007. Process-driven characterization and mapping of seabed habitats, in: Todd, B.J., Greene, H.G. (Eds.), Mapping the Seafloor for Habitat Characterization, Geological Association of Canada, St. Johns, Newfoundland, 2007, p. 171–184.

McIntyre, A. D. e Eleftheriou, A., 2005. Methods for the study of marine benthos. Blackwell Science.

Post, A. L., 2008. The application of physical surrogates to predict the distribution of marine benthic organisms. Ocean e Coastal Management, 51(2), 161-179.

Snelgrove, P.V.R., 1999. Getting to the bottom of marine biodiversity: sedimentary habitats. Bioscience, 49, 129–138.

Van Rein, H., Brown, C. J., Quinn, R., Breen, J., e Schoeman, D., 2011. An evaluation of acoustic seabed classification techniques for marine biotope monitoring over broadscales

(> 1 km 2) and meso-scales (10 m 2–1 km 2). Estuarine, Coastal and Shelf Science, 93(4), 336-349.

Wells, P.G., 1999. Biomonitoring the health of coastal marine ecosystems. The roles and challenges of microscale toxicity test. Marine Pollution Bulletin, 39 (1-2), 39-47.

Zajac, R.N., 2008. Challenges in marine, soft-sediment benthoscape ecology. Landscape Ecology, 23:7–18.

CAPÍTULO 2
ARTIGO

1- CONFIRMAÇÃO DE SUBMISSÃO DO ARTIGO

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Corresponding Author: Mr. Renato Guimarães de Oliveira, M.D.

Corresponding Author's Institution: FEDERAL UNIVERSITY OF BAHIA

First Author: Renato Guimarães de Oliveira, M.D.

Order of Authors: Renato Guimarães de Oliveira, M.D.; José Maria L Dominguez, PhD; Ivan C Lemos Júnior, PhD; Carla Maria M da Silva, PhD

Dear Oliveira,

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O ARTIGO:

EPIBENTHIC MARINE HABITAT MAPPING OF THE NORTHEASTERN PORTION OF THE TODOS OS SANTOS BAY– BAHIA – BRAZIL

Renato Guimarães de Oliveira [a*], José Maria Landim Dominguez [a], Ivan Cardoso Lemos Júnior [a], Carla Maria Menegola da Silva [b]

[a] Laboratório de Estudos Costeiros, INCT AmbTropic. Universidade Federal da Bahia - Rua Barão de Jeremoabo. - Ondina, Salvador, Bahia, Brazil – CEP: 40170-115

[b] Laboratório de Porífera e Fauna Associada. Universidade Federal da Bahia. Instituto de Biologia - Rua Barão de Jeremoabo. - Ondina, Salvador, Bahia, Brazil

* Corresponding author: rgoecv@gmail.com

Abstract

Knowledge on benthic marine communities is ecologically and economically important. The objective of this study was to map epibenthic marine habitats of the northeastern portion of the Todos os Santos Bay (TSB). Satellite images available from Google Earth Pro were used in order to to delimitate optically different areas on the seafloor and intertidal areas. The integration of these images to previous data allowed the individualization of classes of underwater/coastal substrates from which 145 sampling stations were selected for analysis of epibenthic communities. A 0.25 m² square was used in all sampling stations for substrate photo shooting. A Van Veen grab was used to sample sediments from unconsolidated substrate areas. Several different classes of underwater/coastal substrates were found. The analysis of epibenthic data yielded statistically different biological communities among most of the classes of substrate delimitated. By combining all these data, nine epibenthic marine habitats were identified and mapped.

Keywords: epibenthic communities, substrate, remote sensing, ground-truthing

Introduction

Marine habitat distribution patterns provide important information on the nature of physical factors and ecological processes that regulate benthic populations and communities (Levins and Lewontin, 1980; Nanami et al., 2005). These communities are important components of the trophic chain and play an essential role in marine sediment aeration and remobilization, contributing to nutrient remineralization processes and, consequently, to both primary and secondary production processes (Lana et al., 1996). In addition, several species are of direct economic importance as a relevant source of protein to the society and also present considerable pharmacological potential (Lana et al., 1996; Hunt and Vincent, 2006).

Traditional methodologies, such as organism sampling using bottom grab samplers followed by sorting and identification, are still widely used in benthic community studies. However, these procedures can be extremely time consuming and costly.

The development of techniques, such as multibeam bathymetry, side-scan sonar and LIDAR, has reduced these difficulties. In these cases, direct sampling is used only for ground-truthing. However, the use of these techniques does not invalidate the use of traditional direct sampling tools. On the contrary, together these methods can provide better results than if they were used separately. According to Coogan and Populus (2007), at an initial stage this joint approach allows the individualization of different types of substrates for a given study area. It also allows for a later definition of direct sampling stations, enabling continuous habitat mapping, with the integration of physical and biological data. The studies by Markert et al. (2013), LaFrance et al. (2014), Buhl-Mortensen et al. (2015), and Henriques et al. (2015) are examples of investigations that adopted this type of approach.

Benthic marine habitat maps are spatial representations of physically different areas of the seafloor, which are associated with the occurrence of a particular group of species. They are produced based on the evaluation and combination of biotic and abiotic variables, using morphology/relief and distribution of seafloor surface sediment as essential information for habitat classification (Lund and Wilbur, 2007). These maps are important for marine environmental management strategies and for the proposal of new marine protected areas (Roff et al., 2003; Greene et al., 2007). They are also of use to scientific investigation programs regarding benthic ecosystems and seafloor geology, and in the evaluation of living and non-living seafloor resources for both economic and management objectives (Harris and Baker, 2011).

The Todos os Santos Bay (TSB), located along the eastern coast of Brazilian, is the country's second largest bay (1,233 km²), with a surrounding population of approximately 3.5 million inhabitants (IBGE, 2016). Industries and port facilities are also present in the area.

Despite this context of intense human activity, the benthic marine habitats of the TSB had not been mapped until the present moment. The majority of studies already conducted in this area addressed aspects such as chemical contamination, physical and geological oceanography, fisheries, among others. Previous information on the distribution of bottom surface sediment was not greatly detailed (Lessa and Dias, 2009; Dominguez et al. 2012).

Some initiatives to understand the variability and distribution of the benthic fauna in the TBS include the studies by Alves et al. (2004), Pires-Vanin et al. (2011) and Garcia et al. (2014), the latter two of which focused on the northeastern portion of the bay. The traditional approach applied to benthic community investigation was used in these studies. Valle (2013) mapped, in a preliminary approach, the northeastern portion of the seafloor of the TBS with the main objective of understanding the Holocene filling history; while Cruz et al. (2009) mapped the occurrence of reef formations in the bay.

The northeastern portion of the TBS, located between Maré Island and Frades Island (Figure 1) congregates the largest number of industrial activities of the entire bay. Chemical, petrochemical, metallurgical, food products and fertilizer industries represent the main branches of these activities (Hatje et al. 2009). Cases of chronic sediment contamination have been reported for this area, especially by oil-derived polycyclic aromatic hydrocarbons (Venturini and Tommasi, 2004; Martins et al., 2005), trace metals, such as zinc, copper, lead, and cadmium (Wallner-Kersanach et al., 2000; Hatje et al., 2006), and illegal agrochemical substances, such as dichlorodiphenyltrichloroethanes (DDT), dichlorodiphenylethylenes (DDE), and organochlorines (Tavares et al., 1999). Moreover, Maré and Frades islands do not present wastewater treatment plants, so domestic wastewater is directly discharged into mangroves and rivers that flow into the TSB (Hatje et al., 2009). Finally, there are 20 fishing communities within this region and neighboring areas, which are distributed across the municipalities of Madre de Deus, São Francisco do Conde, and Candeias (Soares et al., 2009).

Thus, the northeastern region of the TSB was chosen for epibenthic marine habitat mapping, a paramount tool for marine ecosystem management, representing the first stage for the development of studies and elaboration of management plans for this area.

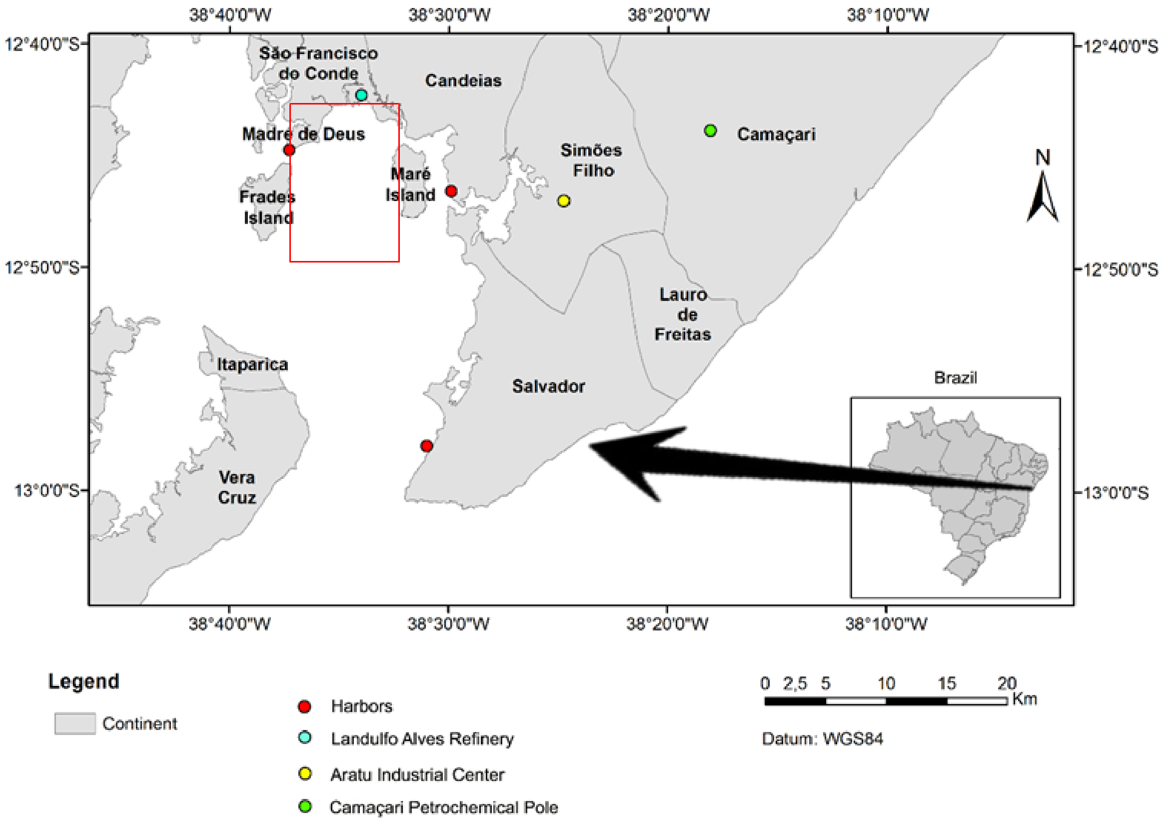

Figure 1. Location of the study area: northeastern portion of the Todos os Santos Bay.

Geological and oceanographic characterization

The Todos os Santos Bay is etched in the rocks of the Cretaceous Recôncavo sedimentary basin. Siltites and massive fine sandstones predominate around Frades and Maré islands (Dominguez and Bittencourt, 2009). The origin of the TSB has been attributed to differential erosion between more friable sedimentary rocks and basement rocks, which are more resistant to erosion (Dominguez and Bittencourt, 2009). During most of the past 500,000 years, the TSB has been exposed to subaerial conditions, which has resulted in deep incised valleys. Only for very short periods of time during interglacial periods, the TSB was completely flooded (Dominguez and Bittencourt, 2009).

The study area is shallow, with some places reaching less than 10 m in depth. However, greater depths can be found along the main channels, reaching 60 m, as in the case of the channel that separates Madre de Deus Island from Frades Island (Figure 2).

Fine sediments predominate on the seafloor of the studied area. Patches of autochthonous biogenic sandy sediments occur in the surroundings of sparse reef bottoms, which are common in the area (Vilas Boas and Bittencourt, 1979; Cruz et al., 2009; Dominguez and Bittencourt, 2009). Sedimentation rates between 2 and 10 mm $year^{-1}$ were reported for these fine sediments (Argollo 1999, 2001).

The circulation in the bay is controlled by tides, which present a semidiurnal pattern (Lessa et al., 2001). The tidal wave is progressively amplified and distorted when entering the TSB, especially in narrower, sinuous, and/or shallower areas (Lessa et al., 2009). The maximum tide range during spring tides on the continental shelf adjacent to the TSB is 1.87 m, while the minimum range during neap tides is 0.98 m. In turn, at the central area of the bay, near Frades Island, the tide range is amplified in 0.55 m during spring tides and 0.25 m during neap tides (Lessa et al., 2009). Significant current velocity variations are observed between spring and neap tides. Maximum velocities of 0.83 m s^{-1} have been reported near the channel that separates Frades Island from Madre de Deus Island (Figure 3). In the remaining regions of the study area, mean values ranging between 0.10 and 0.40 m s^{-1} have been reported during mean ebb tide level, and between 0.10 and 0.30 m s^{-1}, during mean flood tide level. Ebb tides present lower duration and have been associated to higher flow velocities, especially near the surface (Xavier, 2002).

The mean suspended sediment concentration in the area is 1.5 mg / l (Wolgemuth et al., 1981). Mean salinity is approximately 35, and water temperature is always above 20°C (Cirano and Lessa, 2007).

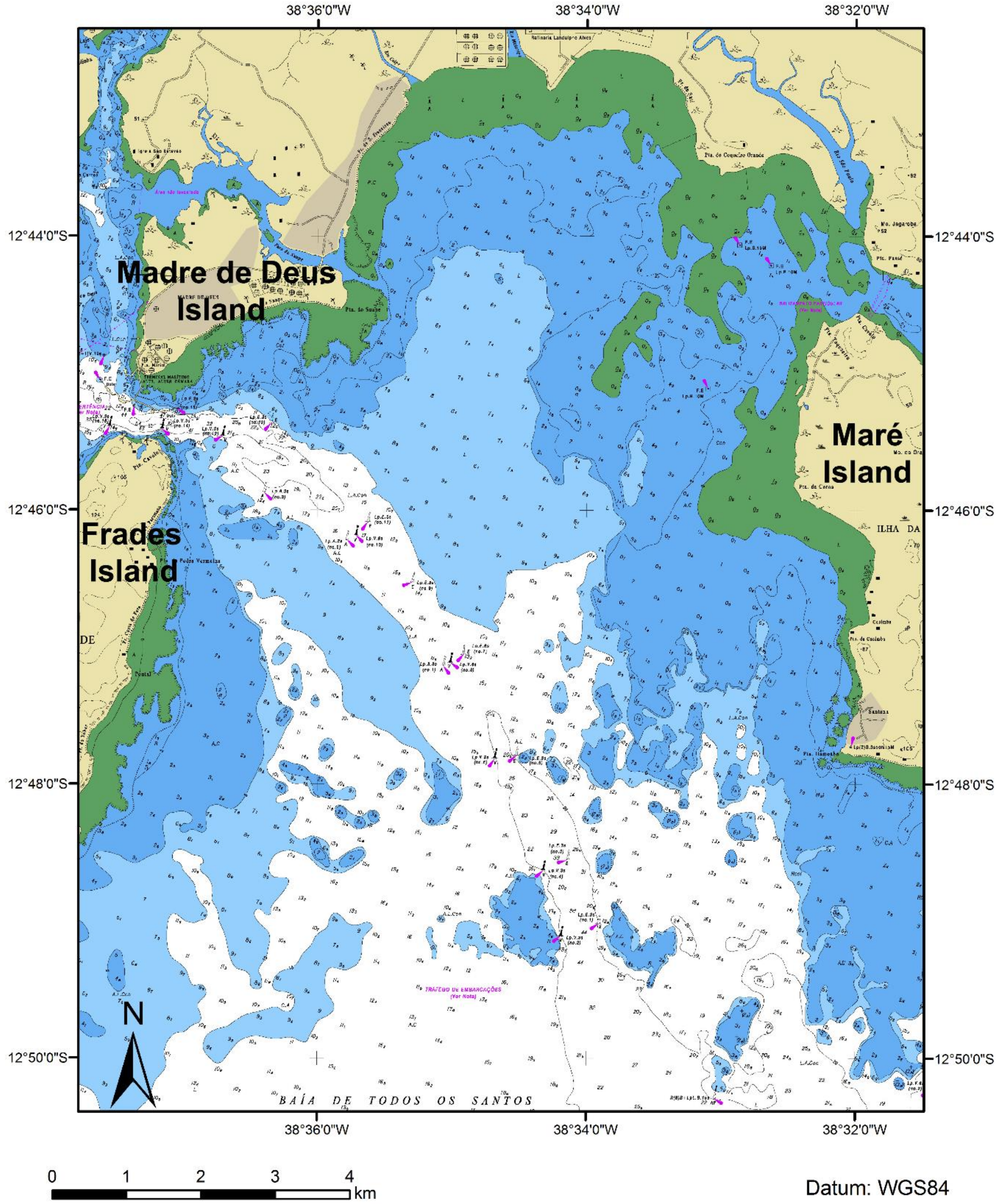

Figure 2. Bathymetric chart No. 1104 produced by the Brazilian Navy (DHN – Directorate of Hydrography and Navigation): northeastern TSB. Color grading indicates depth variation: in white, deeper areas, reaching depths of 60 m; in dark blue, areas with depths ranging between 5 and 10 m; and in light blue, areas shallower than 5 m.

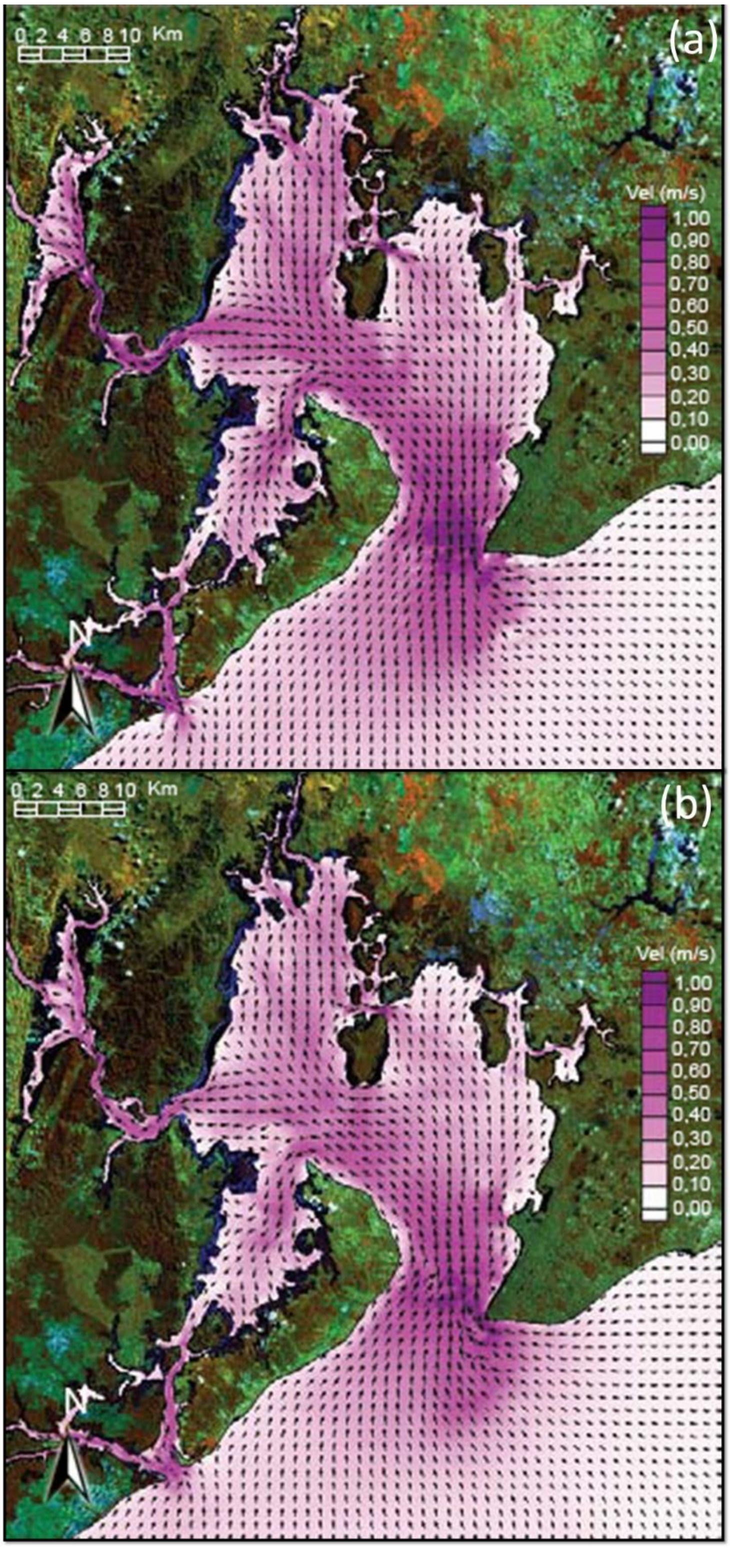

Figure 3. Current field in the Todos os Santos Bay, (a) during mid-ebb tide, and (b) during mid-flood tide; under a spring tide regimen (Lessa et al., 2009).

Material and methods

Remote sensing

Due to the characteristics of the area (area of approximately 150 km², reduced depths, large number of reef bottoms, and good light penetration) satellite images were used to define a map of coastal/marine classes of substrates. High-resolution satellite images available from Google Earth Pro (*Image* © 2016 CNES/ Astrium) were exported at the maximum resolution available (4800 x 2841 pixels) to the software ARCMAP 10.1 and georeferenced. In these images, optically different seafloor and intertidal areas were delimitated. The integration, using GIS, of these images and previous data available for the study area, such as Nautical Chart No. 1104 produced by the Brazilian Navy, high-resolution interpreted seismic profiles (Campos and Dominguez, 2011), sedimentary facies maps (Dominguez et al., 2012), and reef bottom distribution maps (Valle, 2013 and Cruz, 2009), allowed for a detailed individualization of different classes of underwater/coastal substrates, located at maximum depths of approximately 12 m, which represents the limit of visible light penetration in the analyzed images.

Ground-truthing

After the delimitation of different classes of substrates, 145 sampling stations were selected, distributed in a representative way among the various types of substrates so that they would reflect the size and heterogeneity of the previously identified classes. Field campaigns occurred in February, April, May, June, and November 2016.

In infralittoral zones, fieldwork consisted on either SCUBA diving or using a drop camera system. In intertidal zones, sampling was either performed on foot or using small vessels for time optimization. A 0.25 x 0.25 m square was used as the sampling unit in all sampling stations for substrate photos, with the objective of characterizing not only the epibenthic community but also the substrate itself.

Five photo-squares were taken in each sampling station. These were randomly positioned within a 10-m radius, except for 22 stations where low visibility at the bottom compromised image recording. A total of 620 photo-squares were obtained.

The camera’s clock was synchronized with the clock of a GPS Garmin Map 60CSX® receptor located on the vessel. The software HoudahGeo® was used to geolocate each photograph, comparing the time recorded for both the camera and the track log of the GPS.

In sampling stations that presented unconsolidated substrate, sediment was either sampled directly or sampled using a Van Veen grab. Mechanical sieving was used to determine percentages of gravel, sand and mud in all 121 samples of sediment collected. A stereoscopic microscope was used to determine sediment composition by counting 100 grains from previously homogenized sand and gravel fractions from each sample. Grains were classified into two categories: bioclastic and siliciclastic. The data obtained was weighed in importance considering the physical weight of each fraction in the total sample. The IDW (Inverse Distance Weighting) interpolation method was used to interpolate granulometry and sediment composition data, to generate content distribution maps for sand, mud, gravel, and siliciclastic and bioclastic grains in the surface sediment of the seafloor of the studied area.

The software Adobe Photoshop CS® was used to process the photographs obtained, which were later exported to the software Coral Point Count with Excel extensions (CPCe) (Kohler and Gill, 2006). In this software, 100 points per photo-square were drawn over a mesh of 500 possibilities, in which benthic organisms and types of substrate were identified. After the analysis of all photo-squares, a table was generated with the coverage percentage of the identified epibenthic organisms.

Statistical analyses and definition of epibenthic marine habitats

Multivariate statistical methods were used to analyze associations between epibenthic communities and the identified classes of substrate. Initially, photo-squares that did not present biological records (7) were excluded from the analyses. The log (X+1) transformation was applied to the biological data for approximation to a normal distribution. The Bray-Curtis Dissimilarity Index (Clarke and Warwick, 1994) was then used for a non-Metric Multidimensional Scaling analysis (mMDS) of the cover data of the epibenthic organisms identified. The ANOSIM test (Clarke, 1993) was used in order to test the significance of differences in epibenthic community composition among the various classes of substrate mapped. In addition, the software Similarity Percentage (SIMPER) was used with the objective of indicating which organisms were mainly responsible for similarities within each group (most common organisms), and which organisms presented the greatest contribution to dissimilarity among these groups (most different organisms). The software Microsoft Office Excel 2010 and PRIMER 6.0 for Windows were used for data processing.

The integration of biological and physical data allowed the elaboration of the final habitat map of the study area. A synthesis of the methodological process is presented in Figure 4.

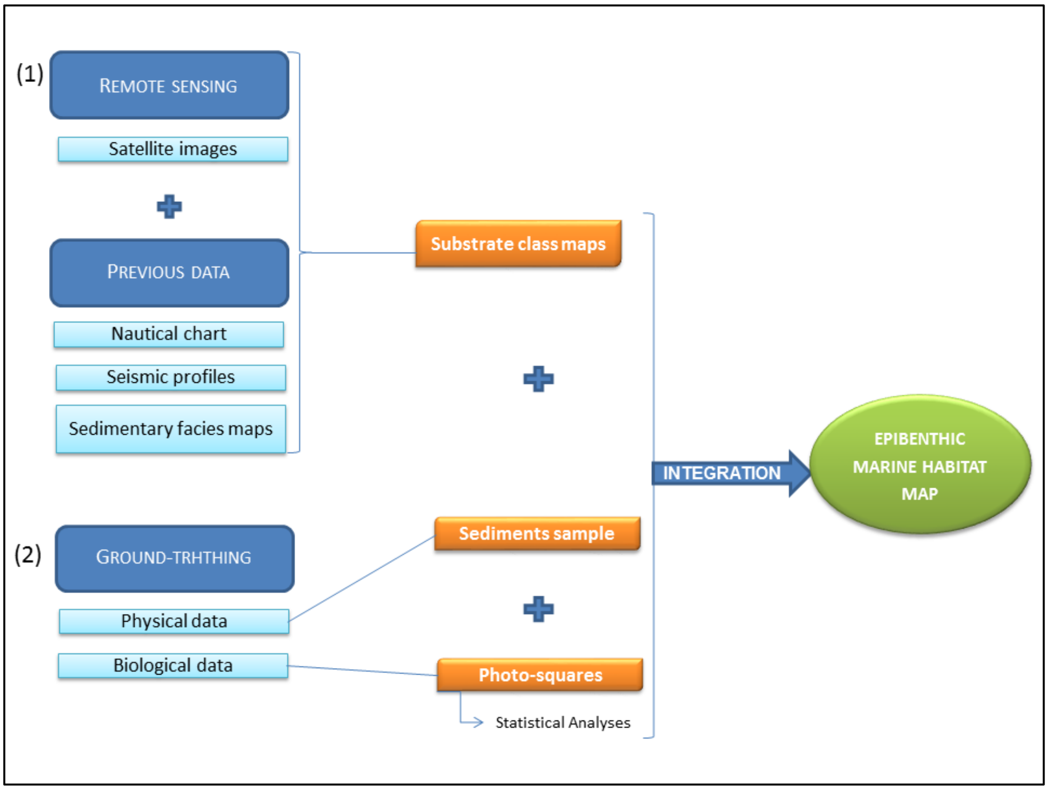

Figure 4. Flowchart with the methodological stages of the present study.

Results

Substrate Classes

Analysis of high-resolution images and their integration to previous data indicated the presence of 8 classes of substrate in the study area (Figures 5 and 6): Class A – hard substrate entirely colonized by organisms; Class B – intertidal rocky slabs; Class C – seafloor covered by soft macroalgae; Class D – predominantly sandy seafloor (> 50% sand); Class E – tidal flats; Class F – predominantly muddy seafloor (> 50% mud); Class G – mangrove forest; Class H – apicum. Fieldwork campaigns confirmed that the classes that had been previously identified through satellite images did in fact correspond to different substrates and geomorphologies.

Photo-squares

A total of 15 groups of organisms (hard corals, fire corals, black corals, Zoantharia, Octocorals, Echinodermata, Porifera, Crustacea, soft macroalgae, calcareous macroalgae, Mollusca, Ascidiacea, Bryozoa, Cyanobacteria, and Polychaeta) and two indicators of biological activity (biofilm and bioturbation) were identified from the analysis of the 620 photo-squares.

The term biofilm was used to describe a fine reddish, often brownish, layer that covers the water-sediment interface, similarly to “mucus”. Though its source is unknown, it is most likely of biological origin.

Signs of bioturbation represent any type of sediment disturbance caused by the presence of organisms resulting from faunal activities, such as feeding, excavation and locomotion (Posey, 1987; Findlay et al., 1990; Hall, 1994; Kinoshita et al., 2003; Friedrichs et al., 2009; Araújo et al., 2012). These signs indicate biological activities and are mainly associated with crustaceans, mollusks, polychaetes, and fish (Meysman et al., 2006).

Table 1 shows the mean percentage and standard deviation of the coverage of the different groups of epibenthic organisms identified through photo-squares for each one of the classes of substrate found in the study area. No sampling activities were performed for classes G (Mangrove forest) and H (Apicum), since their area of occurrence was not restricted to the study area and are distributed over several other regions in the TSB. They were only delimited during photointerpretation in order to complement the mapped area.

The group of organisms that presented the largest cover for the total sampled area was the “soft macroalgae” group (fleshy and filamentous macroalgae), covering 22% of the area. On the other hand, the “Polychaeta” group presented the smallest area, covering only 0.04% of the epibenthic environment. The highest taxa richness was observed for substrate class A, which was the only class where all identified groups were present. Class F presented the lowest taxa richness, in which only biological activity indicators, such as biofilm and bioturbation, were found (Table 1).

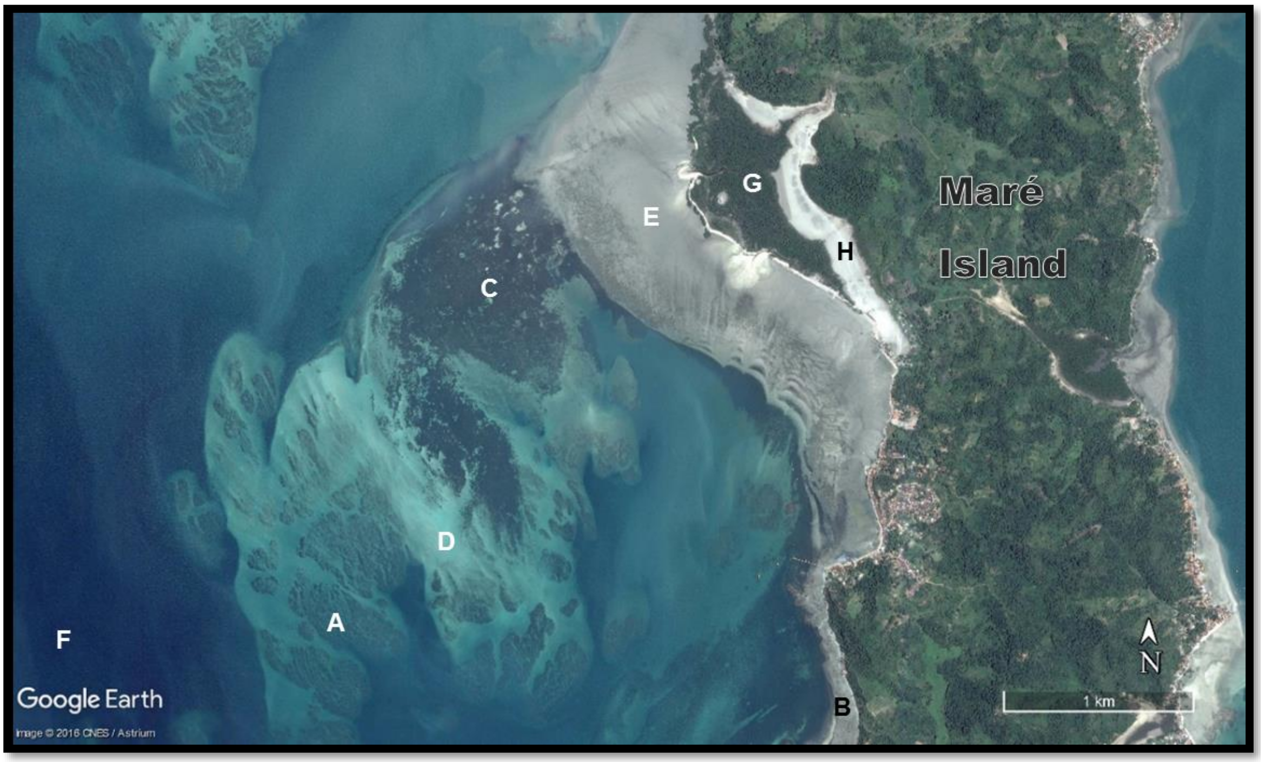

Figure 5. Examples of optical responses to the various classes of substrate individualized during photointerpretation: (a) Class A – hard substrate entirely colonized by organisms; (b) Class B – intertidal rocky slabs; (c) Class C – seafloor covered by soft macroalgae; (d) Class D – predominantly sandy seafloor (> 50% sand); (e) Class E – tidal flats; (f) Class F – predominantly muddy seafloor (> 50% mud); (g) Class G – mangrove forest; and (h) Class H – apicum.

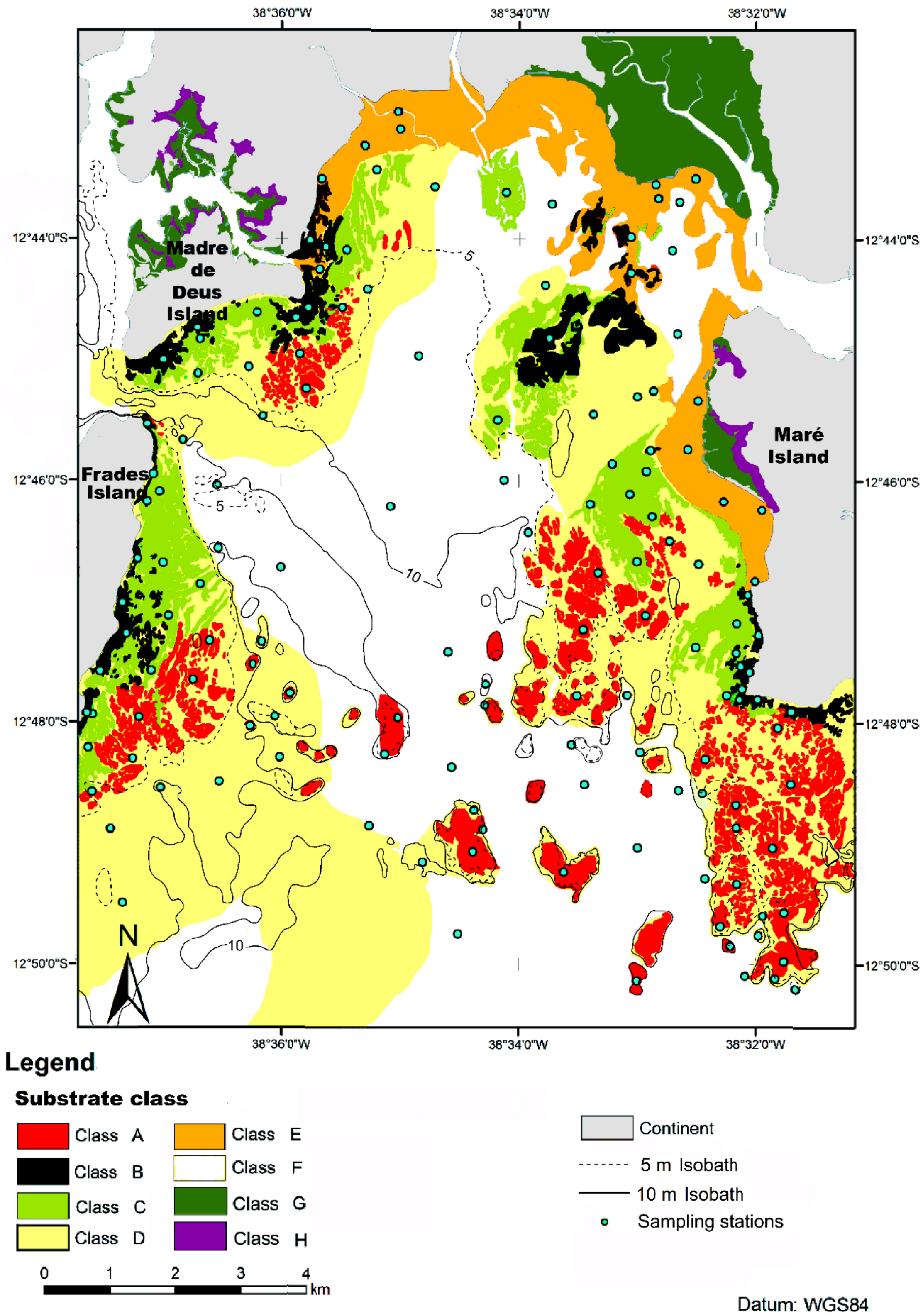

Figure 6. Map of substrate classes produced from the integration of high-resolution satellite image analysis and previous data. Points show the location of sampling stations visited during field campaigns. Class A – hard substrate entirely colonized by organisms; Class B – intertidal rocky slabs; Class C – seafloor covered by soft macroalgae; Class D – predominantly sandy seafloor (> 50% sand); Class E – tidal flats; Class F – predominantly muddy seafloor (> 50% mud); Class G – mangrove forest; Class H – apicum.

Table 1. Coverage percentage of groups of epibenthic organisms for each substrate class (X is the mean % of occupied area in photo-squares, and s is the standard deviation).

		Class A	Class B	Class C	Class D	Class E	Class F
Hard coral	$\bar{X}$	5,2	0,01	0,01	0,03	0,00	0,00
	s	15,03	0,088	0,10	0,32	0,00	0,00
Fire Coral	$\bar{X}$	1,64	0,00	0,00	0,00	0,00	0,00
	s	9,81	0,00	0,00	0,00	0,00	0,00
Black coral	$\bar{X}$	0,36	0,00	0,00	0,00	0,00	0,00
	s	1,67	0,00	0,00	0,00	0,00	0,00
Zoantharia	$\bar{X}$	18,16	0,12	0,00	0,00	0,00	0,00
	s	26,24	0,78	0,00	0,00	0,00	0,00
Octocoral	$\bar{X}$	4,36	0,00	0,00	0,04	0,00	0,00
	s	11,65	0,00	0,00	0,48	0,00	0,00
Echinodermata	$\bar{X}$	0,01	0,01	0,02	0,31	0,00	0,00
	s	0,09	0,09	0,21	1,88	0,00	0,00
Porifera	$\bar{X}$	11,53	1,60	3,32	1,71	0,00	0,00
	s	13,12	4,63	6,21	4,57	0,00	0,00
Crustacea	$\bar{X}$	0,10	4,05	0,02	0,03	0,00	0,00
	s	0,42	9,46	0,21	0,16	0,00	0,00
Soft macroalgae	$\bar{X}$	9,33	30,79	73,5	6,7	17,7	0,00
	s	20,91	24,43	24,82	14,04	14,93	0,00
Calcareous macroalgae	$\bar{X}$	3,35	2,28	0,6	1,82	0,00	0,00
	s	7,30	6,79	1,67	4,18	0,00	0,00
Molusca	$\bar{X}$	0,24	4,62	0,23	0,69	0,96	0,00
	s	0,88	9,24	0,75	1,92	2,48	0,00
Ascidiacea	$\bar{X}$	0,21	0,05	0,01	0,01	0,00	0,00
	s	0,81	0,45	0,10	0,11	0,00	0,00
Bryozoa	$\bar{X}$	0,07	0,11	0,00	0,03	0,00	0,00
	s	0,36	0,77	0,00	0,21	0,00	0,00
Cyanobacteria	$\bar{X}$	3,63	0,00	0,00	0,00	0,00	0,00
	s	7,46	0,00	0,00	0,00	0,00	0,00
Polychaeta	$\bar{X}$	0,01	0,08	0,01	0,02	0,00	0,00
	s	0,12	0,45	0,10	0,14	0,00	0,00
Biofilm	$\bar{X}$	1,40	0,06	3,32	22,34	0,00	49,85
	s	6,55	0,70	7,21	25,35	0,00	22,88
Bioturbation	$\bar{X}$	0,44	0,21	0,39	1,77	1,60	4,49
	s	1,02	0,73	0,87	1,82	1,46	2,65

Surface Sediment Texture

Figure 7 shows the spatial distribution of the sand, mud and gravel contents of seafloor surface sediments in the study area. Apart from Class F, sand predominated in all remaining substrate categories mapped (Table 2). Patches of coarser sediments occurred mainly in the surroundings of, and often on, rocky substrates. Classes G and H, as previously mentioned, were neither visited nor sampled. Apart from Class E, surface sediment was predominantly comprised by biogenic grains. Figure 8 shows the spatial distribution of bioclastic grain content in the seafloor surface sediment, and Table 3 presents the mean values of bioclastic grain content for each class of mapped substrate.

Table 2. Mean contents of gravel, sand, and mud fractions in the seafloor surface sediments of each class of substrate mapped.

Substrate class	% gravel	% sand	% mud
A (n = 22)	14.48 (±12.64)	75.61 (±18.24)	9.91 (±17.60)
B (n = 6)	8.74 (±5.94)	80.25 (±9.20)	11.01 (±8.82)
C (n = 19)	6.02 (±6.05)	87.40 (±8.07)	6.58 (±6.53)
D (n = 35)	13.58 (±13.14)	77.02 (±13.38)	9.40 (±8.81)
E (n = 14)	4.62 (±4.54)	78.16 (±5.47)	17.22 (±1.74)
F (n = 25)	0.29 (±0.65)	14.83 (±12.77)	84.89 (±12.85)

Table 3. Mean values of bioclastic and siliciclastic grain content in the seafloor surface sediments of each class of substrate mapped.

Substrate class	% siliciclastic grain	% bioclastic grain
A (n = 22)	3,03 (±6,94)	87,06 (±18,60)
B (n = 6)	41,98 (±38,68)	47,00 (±44,35)
C (n = 19)	26,58 (±23,57)	66,84 (±23,26)
D (n = 35)	21,91 (±22,82)	68,68 (±25,57)
E (n = 14)	67,94 (±25,47)	14,83 (±15,07)
F (n = 25)	3,32 (±3,58)	11,7 (±11,55)

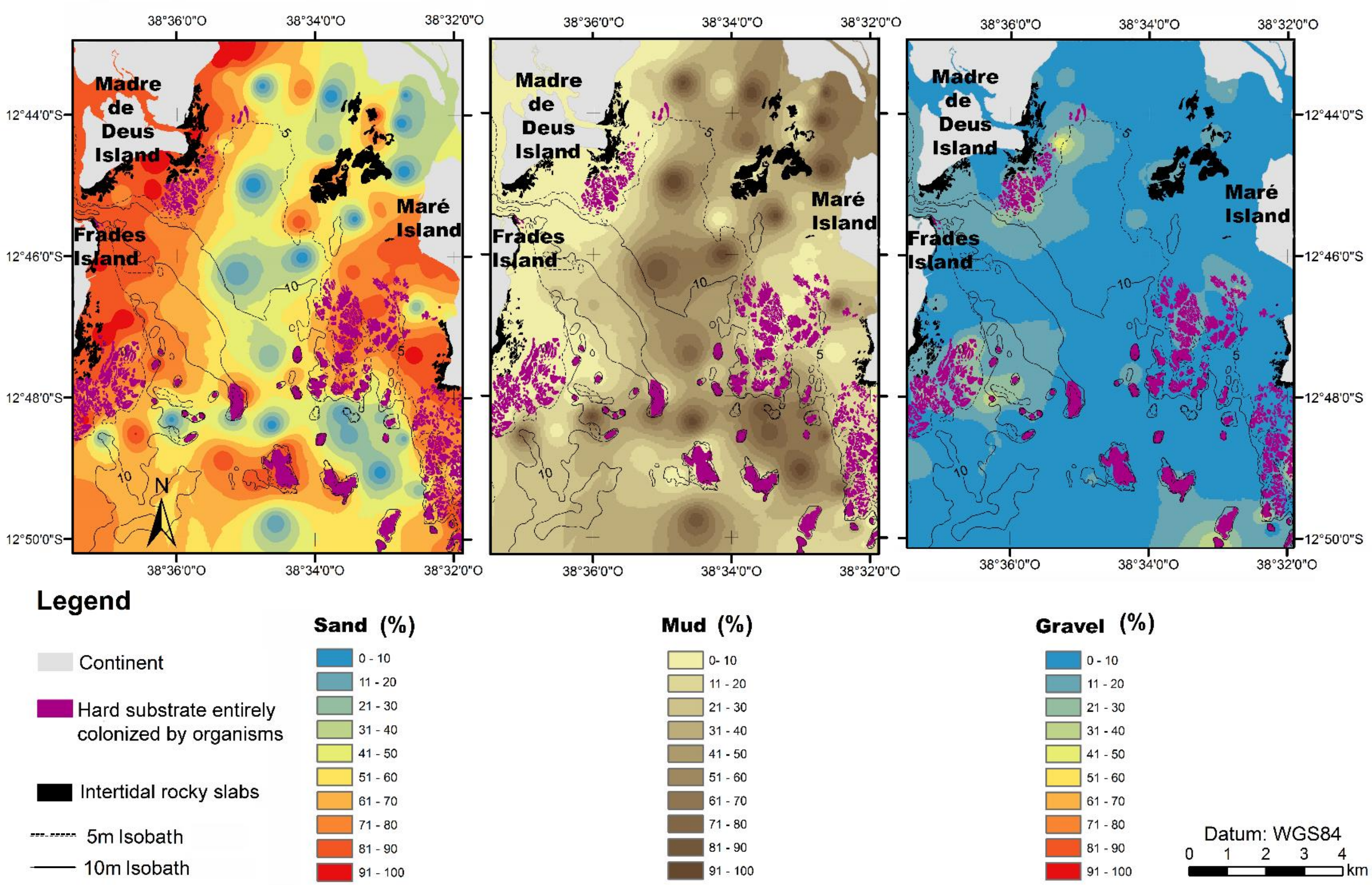

Figure 7. Distribution of sand, mud, and gravel contents in seafloor surface sediments.

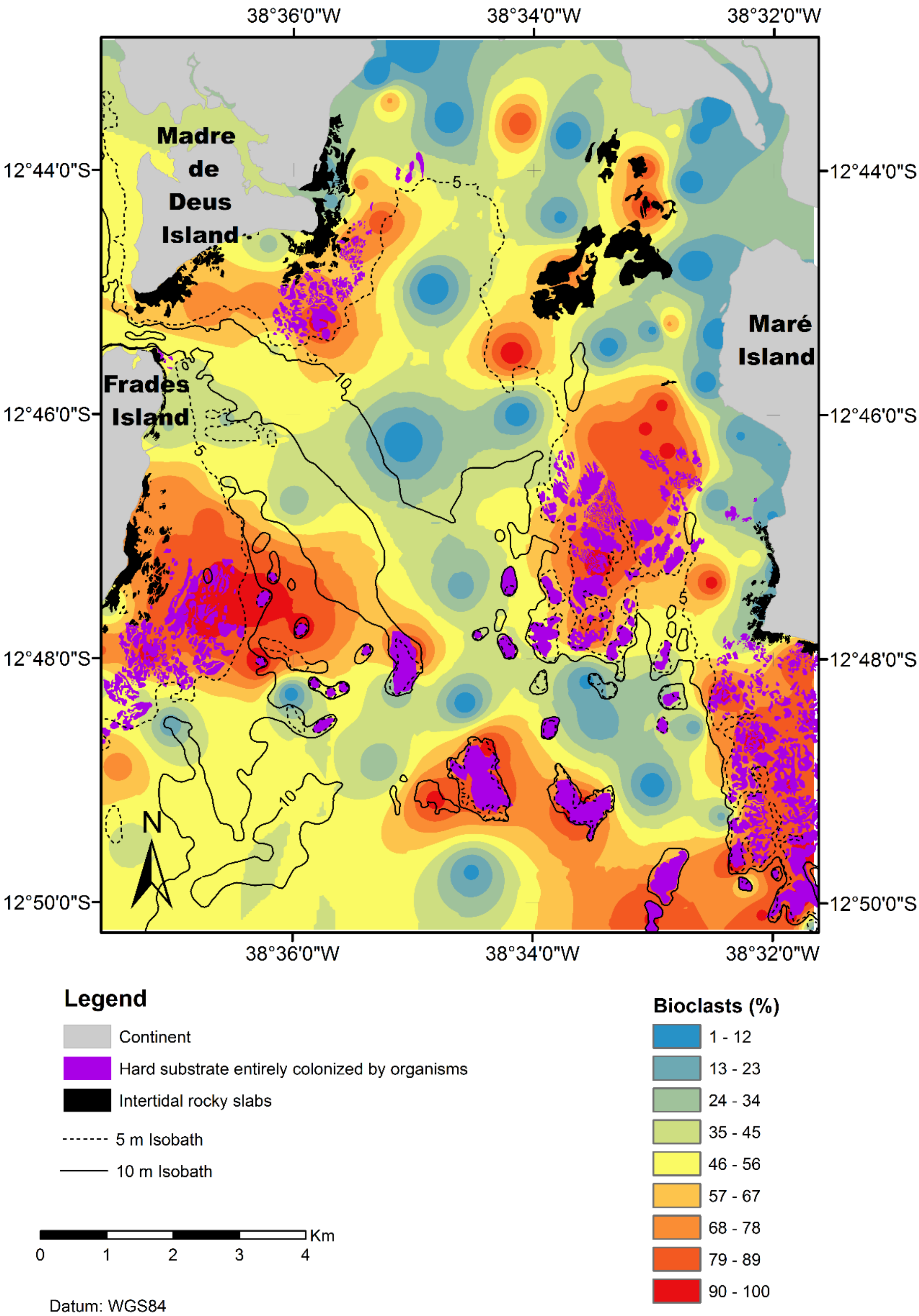

Figure 8. Spatial distribution of bioclast content in seafloor surface sediments.

Statistical Analyses

The non-Metric Multidimensional Scaling analysis (nMDS) of the epibenthic organism coverage percentage found in each class of substrate was applied to observe how these organisms were grouped (Figure 9).

The Analysis of Similarity (ANOSIM) indicated significant differences in the composition of epibenthic communities among the various classes of substrate (overall R = 0.45; p = 0.001), except between D and F (Table 4).

Table 4. Analysis of Similarity (ANOSIM) of epibenthic organism coverage from each of the classes of substrate mapped (significant test results are presented in boldface).

Paired tests	**R**	**p**
Classes A x B	0,579	**0,001**
Classes A x C	0,520	**0,001**
Classes A x D	0,474	**0,001**
Classes A x E	0,599	**0,001**
Classes A x F	0,762	**0,001**
Classes B x C	0,151	**0,001**
Classes B x D	0,486	**0,001**
Classes B x E	0,096	**0,015**
Classes B x F	0,899	**0,001**
Classes C x D	0,393	**0,001**
Classes C x E	0,496	**0,001**
Classes C x F	0,941	**0,001**
Classes D x E	0,232	**0,001**
Classes D x F	- 0,051	0,98
Classe E x F	0,915	**0,001**

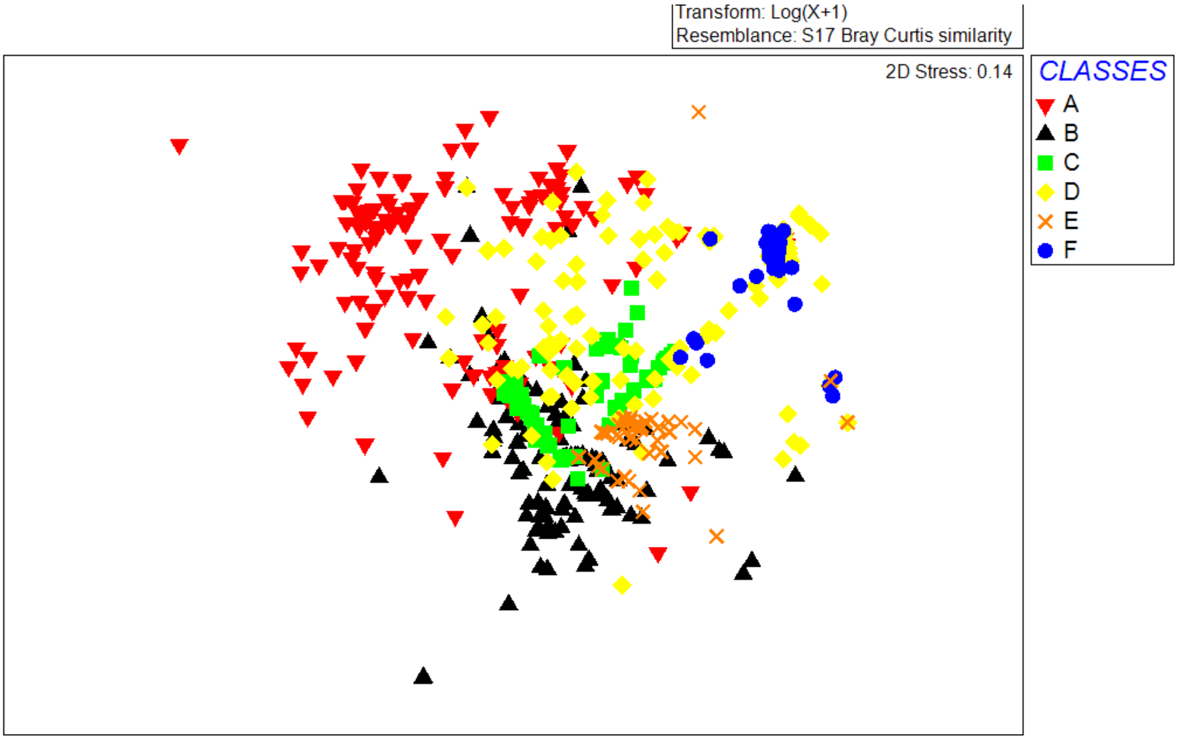

Figure 9. Results of the nMDS analysis of epibenthic fauna coverage for the classes of substrate mapped. Class A – hard substrate entirely colonized by organisms; Class B – intertidal rocky slabs; Class C – seafloor covered by soft macroalgae; Class D – predominantly sandy seafloor (> 50% sand); Class E – tidal flats; Class F – predominantly muddy seafloor (> 50% mud).

The Similarity Percentage analysis (SIMPER) showed that mean faunistic similarity for the study area was 56.93%. Classes of substrate F and C presented the highest similarity mean values (78.73% and 72.67%, respectively). On the other hand, classes A and D, revealed the lowest mean similarities (34.34% and 38.98%, respectively) (Table 5). Regarding dissimilarity, the highest observed value was between classes of substrate B and F (95.35%), while the lowest was between classes C and E (46.34%).

In general, the high dissimilarity values found in the SIMPER analysis (Table 6) corroborated the separation of these classes of substrate, demonstrated by the ANOSIM analysis. However, between some classes, such as B and C, and C and E, for example, the mean dissimilarity values were low (46.39% and 46.34%, respectively) but significant enough to be separated through the ANOSIM analysis. In turn, while classes of substrate D and F presented higher mean dissimilarity (51.38%), this value was not significant enough to discriminate these classes through the ANOSIM analysis.

Table 5. SIMPER. Similarity Percentages and contribution of the main taxa of epibenthic organisms to the similarity of the substrate classes mapped.

Substrate class	Similarity (%)	Taxa	Contribution (%)
A	34,34	Porifera Zoantharia Calcareous macroalgae Cyanobacteria Soft macroalgae	46,32 19,80 11,59 6,39 5,93
B	51,47	Soft macroalgae Mollusca	80,24 10,05
C	72,67	Soft macroalgae	91,53
D	38,98	Biofilm Bioturbation Soft macroalgae	51,07 25,08 12,20
E	65,39	Soft macroalgae Bioturbation	76,54 21,16
F	78,73	Soft macroalgae Bioturbation	71,40 28,43

Table 6. SIMPER. Dissimilarity Percentages and contribution of the main taxa of epibenthic organisms to the dissimilarity of the substrate classes mapped.

Substrate classes	Dissimilarity (%)	Taxa	Contribution (%)
A x B	83,36	Soft macroalgae Porifera Zoantharia	22,74 15,68 13,08
A x C	78,94	Soft macroalgae Porifera Zoantharia	31,81 14,75 13,23
A x D	84,24	Biofilm Porifera Zoantharia Soft macroalgae	18,18 15,58 13,28 11,86
A x E	87,59	Soft macroalgae Porifera Zoantharia	22,07 18,90 14,27
A x F	92,64	Biofilm Porifera Zoantharia Bioturbation	27,20 15,93 12,13 10,65
B x C	46,39	Soft macroalgae Mollusca Porifera Crustacea Biofilm	27,12 16,31 16,09 12,51 10,62
B x D	79,94	Soft macroalgae Biofilm Mollusca	28,22 23,73 10,83
B x E	51,14	Soft macroalgae Mollusca Bioturbation Crustacea	29,91 19,87 17,26 14,19
B x F	95,35	Biofilm Soft macroalgae Bioturbation	34,08 28,30 13,65
C x D	72,90	Soft macroalgae Biofilm Porifera	42,03 23,72 10,79

C x E	46,34	Soft macroalgae Bioturbation Porifera Biofilm	40,99 17,35 15,22 12,18
C x F	85,48	Soft macroalgae Biofilm Bioturbation	43,62 31,37 13,83
D x E	72,02	Soft macroalgae Biofilm Bioturbation	32,59 31,79 10,67
D x F	51,38	Biofilm Soft macroalgae Bioturbation	39,39 17,96 16,46
E x F	80,37	Biofilm Soft macroalgae Bioturbation	48,69 34,35 11,99

Characterization of classes of substrate and associated epibenthic organisms

Class A – Hard substrate entirely colonized by organisms

Class A corresponded to rocky substrates permanently underwater and entirely colonized by encrusting benthic organisms (Figure 10). This class occurred at depths ranging between 1.5 and 11 meters in relation to the base level of the nautical charts produced by the Brazilian Directorate of Hydrography and Navigation (DHN). The following epibenthic groups were found for this class: hard corals, fire corals, black corals, Zoantharia, Octocorals, Echinodermata, Porifera, Crustacea, soft macroalgae, calcareous macroalgae, Mollusca, Ascidiacea, Bryozoa, Cyanobacteria, and Polychaeta. Biological activity indicators (biofilm and bioturbation) were also observed. The SIMPER analysis (Table 5) showed that the composition of the epibenthic community associated with this class of substrate was similar in 34.34%. The main common organisms were Porifera, Anthozoans, calcareous macroalgae, cyanobacteria, and soft macroalgae, with similarity contributions of 46.32%, 19.80%, 11.59%, 6.39%, and 5.93%, respectively.

Although substrate class A is not of biological origin (Valle, 2013), meaning the structures that compose the class are not bioconstructions, the predominance of biogenic sediments covering this type of substrate was noteworthy, comprising an average of 87.06%

of surface sediments. Regarding texture, the sediment analyzed presented mean content values of 14.48% gravel, 75.61% sand, and 9.91% mud.

Substrate class A occurred in the southern and middle-western portions of Maré Island, in the southeastern portion of Frades Island, in the eastern portion of Madre de Deus Island, and in a few areas of the central portion of the study area.

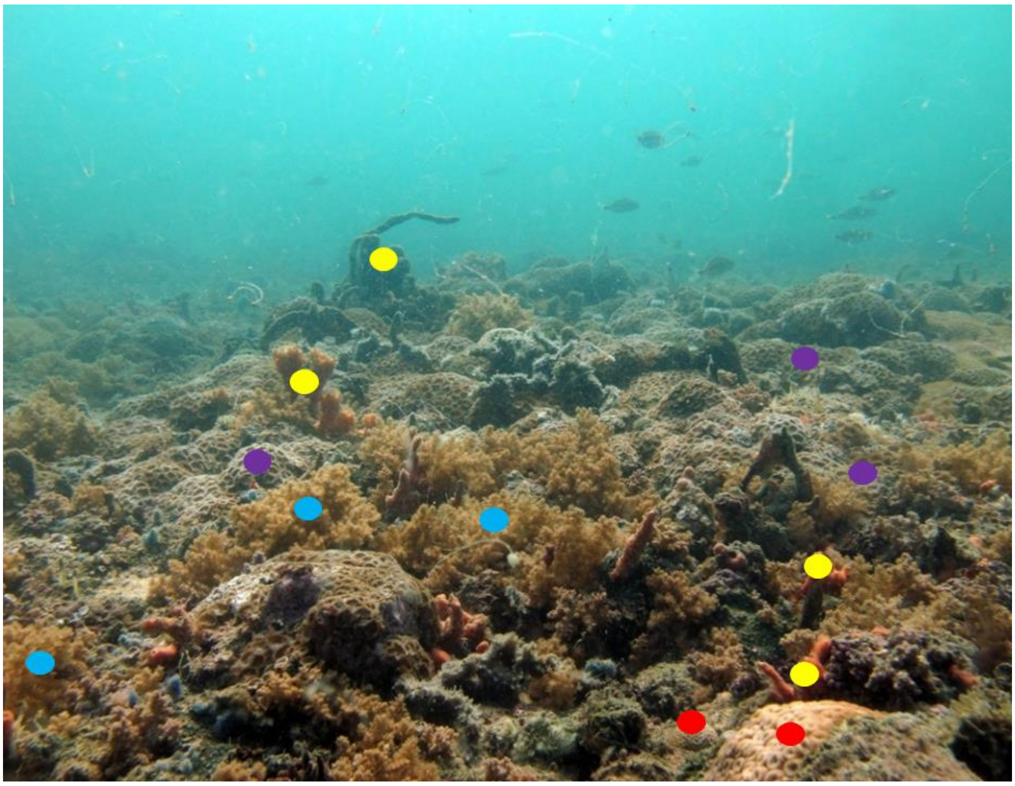

Figure 10. Class A (hard substrate entirely colonized by organisms). Photo taken at a depth of 4 m. Red dots indicate hard corals; blue dots, Octocorals; yellow dots, Porifera; and purple dots, Zoantharia.

Class B – Intertidal rocky slabs

This class consisted of rocky slabs (marine-cut terraces) that are exposed during low tides (Figure 11). The epibenthic groups found in these areas were: hard corals, Zoantharia, Echinodermata, Porifera, Crustacea, soft macroalgae, calcareous macroalgae, Mollusca, Ascidiacea, and Polychaeta. Biological activity indicators (biofilm and bioturbation) were also observed (Figure 12). The SIMPER analysis showed that the epibenthic community coverage in this class of substrate was similar in 51.47%. The groups that contributed the most to this similarity value were soft macroalgae and Mollusca, with contribution values of 80.24% and 10.05%, respectively.

The portions of these slabs that remain exposed to subaereous conditions for longer periods of time were not densely colonized.

Locally, a thin layer of sediments was observed in the surroundings of and burying these slabs. On average, these sediments consisted of 41.98% siliciclastic grains and 47% biogenic grains. These sediments presented mean percentages of 8.74% gravel, 80.25% sand, and 11.01% mud.

This class was found bordering the eastern portion of Frades Island, in the southern and southeastern portions of Maré Island, and in the northern portion of the study area. The presence of tide pools was common for this class.

Figure 11. Class B (intertidal rocky slabs) exposed during a low tide, located at the southeastern margin of Frades Island.

Figura 12. Example of photo-squares obtained for Class B (intertidal rocky slabs). Green dots indicate soft macroalgae; blue dots, Crustacea; yellow, Porifera; purple, Zoantharia; white, Mollusca; and orange, calcareous macroalgae.

Class C – Seafloor covered by soft macroalgae

This substrate occurred in the infralittoral zone at depths ranging between 0.5 and 6 meters, below the base level of the nautical charts produced by the DHN (Figure 13). The following epibenthic groups were found in this class: hard corals, Echinodermata, Porifera, Crustacea, soft and calcareous macroalgae, Mollusca, Ascidiacea, Polychaeta, and biological activity indicators (biofilm and bioturbation) (Figure 14). The SIMPER analysis showed similarity of 72.67% in epibenthic community coverage. The soft macroalgae group contributed with 91.53% of this similarity.

Mean values of sediment composition were 6.02% gravel, 87.40% sand, and 6.58% mud, which consisted of a mean value of 26.58% siliciclastic grains and 66.84% bioclastic grains.

This class of substrate was found bordering the entire eastern portion of Frades and Madre de Deus islands, the western portion of Maré Island, and the middle-northern portion of the study area.

Figure 13. Class C (seafloor covered by soft macroalgae). Photo taken at a depth of 3 m, at the eastern portion of Frades Island.

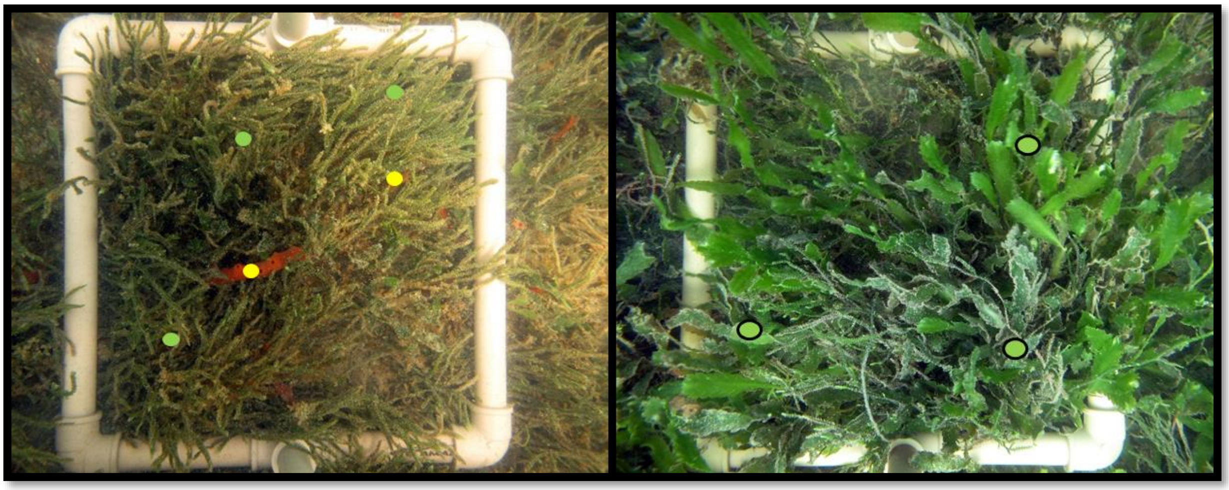

Figure 14. Examples of photo-squares obtained for Class C (seafloor covered by soft macroalgae). Green dots indicate soft macroalgae; yellow dots, Porifera.

Class D – Predominantly sandy seafloor with variable amounts of gravel and mud

Class D corresponded to regions where unconsolidated substrate was found at the transition between consolidated substrates and areas of the seafloor where muddy sediments predominated. This class was found at depths ranging between 1 and 44 meters, below the base level of the nautical charts produced by the DHN.

The epibenthic community found in Class D included the following groups: hard corals, Octocorals, Echinodermata, Porifera, Crustacea, soft and calcareous macroalgae, Mollusca, Ascidiacea, Bryozoa, Polychaeta, and biological activity indicators - biofilm and bioturbation (Figure 15).

The SIMPER analysis indicated that the benthic community found in substrate class D presented 38.98% of similarity. The biological activity categories contributed the most to this value (51.07% biofilm and 25.08% bioturbation), followed by soft macroalgae (12.20%) and Porifera (4.67%).

The predominant sediment of this type of substrate was sand (77.02%), with lower contents of gravel (13.58%) and mud (9.4%). Locally, however, the content of gravel was occasionally equal to or even higher than the content of sand. Sediment was composed by a mean value of 21.91% siliciclastic grains and 68.68% bioclastic grains.

In general, this class was found near rocky outcrops (classes A and B), where significant amounts of biodetritic sediments were present (Figure 16). Locally, large areas of this class were found with the presence of ripple marks, with or without bioturbation (Figure 17).

This class bordered the eastern portions of Frades Island and Madre de Deus Island, stretching until the central portion of the study area, the southern and western portion of Maré Island, and the middle-northern region of the study area.

Figure 15. Examples of photo-squares obtained for Class D (predominantly sandy seafloor). Brown dots indicate biofilm; grey dots, signs of bioturbation; yellow dots, Porifera; green dots, soft macroalgae; and black dots, Echinodermata.

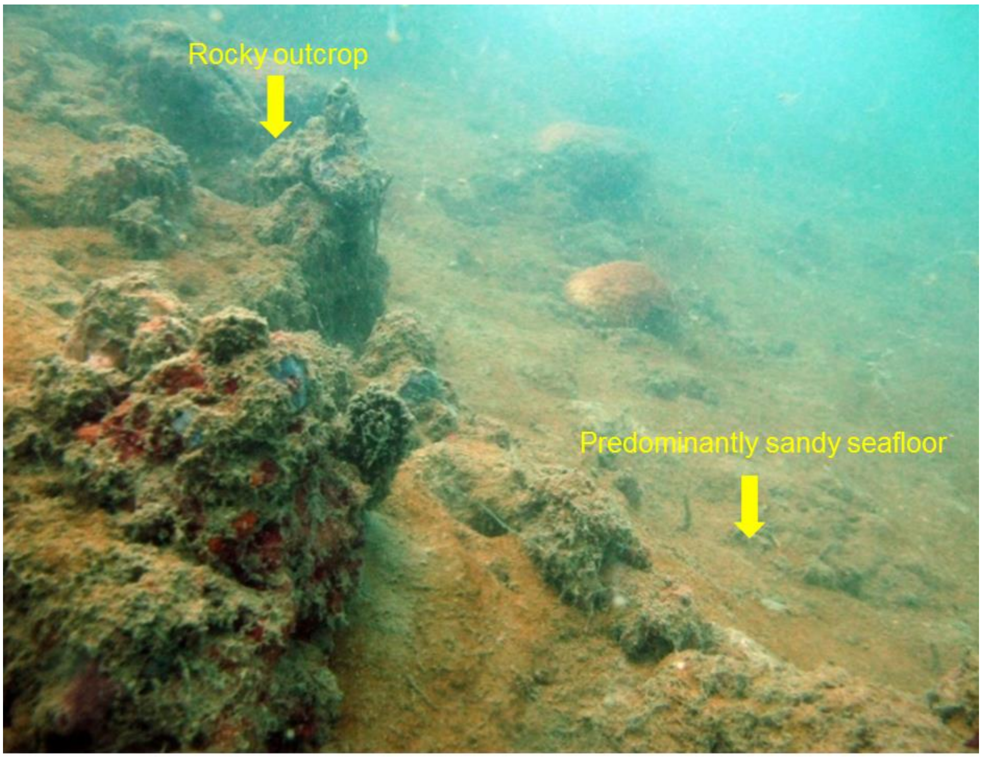

Figure 16. Class D (predominantly sandy seafloor) found near rocky outcrops. Photo taken at the southern portion of Maré Island at a depth of 6 m.

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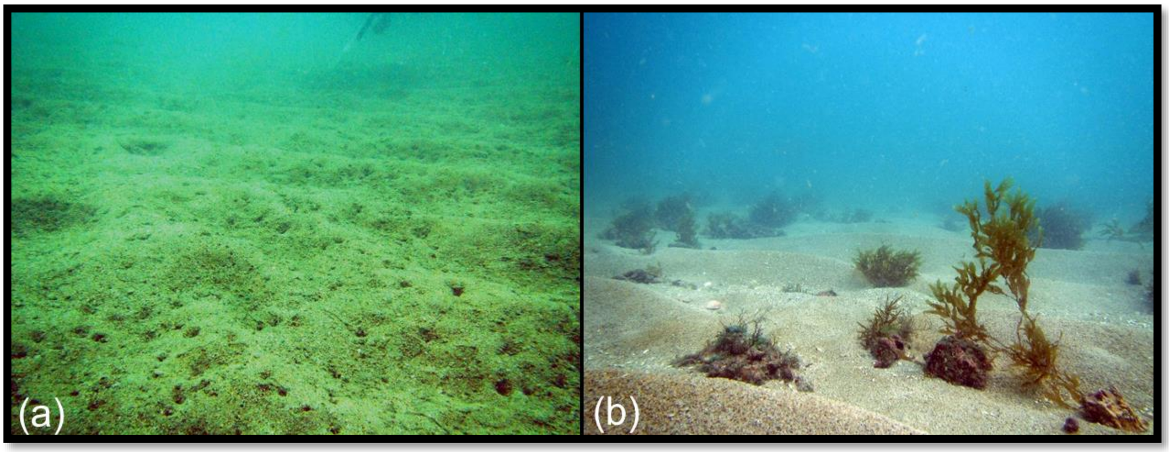

Figure 17. Class D (predominantly sandy seafloor). Example of ripple marks found locally, which could either present or not signs of bioturbation. (a) Middle-southern region of the study area at a depth of 11 m; (b) Eastern portion of Frades Island at a depth of 3 m.

Class E – Tidal flats

This class consisted of tidal flats that were predominantly composed by sand, although, locally, there were areas dominated by mud.

The epibenthic groups found in this type of substrate were: soft macroalgae, Mollusca, and signs of bioturbation (Figure 18). The presence of crabs and swimming crabs (Crustacea) was particularly noteworthy in this substrate class. However, these organisms were not recorded in photo-squares, due to the wandering habit of these animals and because they become scared by human approximation. The SIMPER analysis showed similarity of 65.39% for epibenthic community coverage. Soft macroalgae contributed with 76.54% of this similarity, while the biological activity indicator present (bioturbation) contributed with 21.16%.

Mean values of sediment composition in this class were 4.62% gravel, 78.16% sand, and 17.22% mud. Unlike the other substrate classes, siliciclastic grains predominated in this class, with mean contents of 67.94%. Moreover, ripple marks were commonly found (Figure 19).

Tidal flats were found bordering the continent at the northern portion of the study area and in the western surroundings of Maré Island. This class of substrate was generally associated with mangrove forests and occurred near extremely urbanized areas, with intense industrial activity in the surroundings, intense mollusk harvesting, and noteworthy presence of domestic waste.

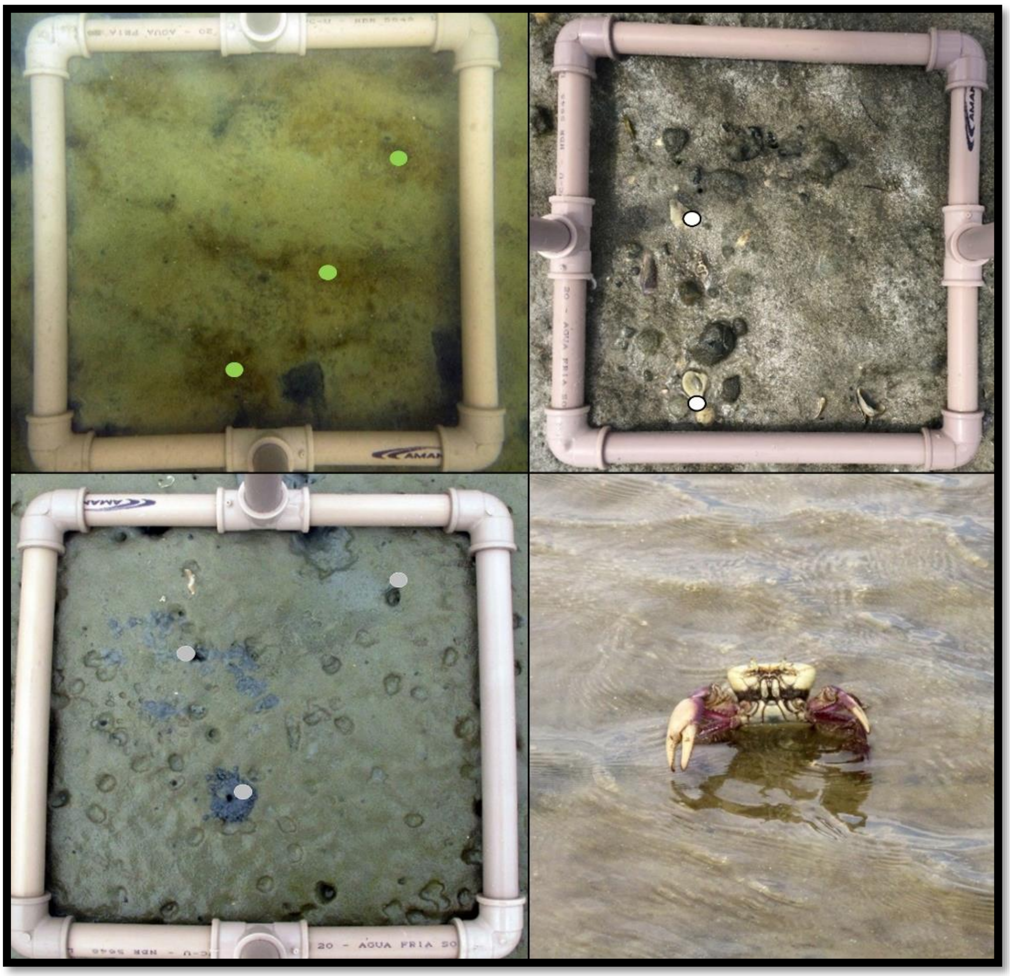

Figure 18. Examples of photo-squares obtained for Class E (tidal flats). Green dots indicate soft macroalgae; white dots, Mollusca; and grey dots, signs of bioturbation. Crustaceans were very common in this class of substrate, although they were not represented in photo-squares due to their wandering behavior.

Figure 19. Class E (tidal flats). Northwestern portion of the study area, near the facilities of the Landulfo Alves oil refinery.

Class F – Predominantly muddy seafloor

This type of substrate was found at depths ranging between 0.5 and 32 m below the base level of the nautical charts produced by the DHN. Epibenthic organism richness in this type of substrate was very low and only biological activity indicators (biofilm and bioturbation) were observed (Figure 20). The high similarity value (78.73%) found through the SIMPER analysis resulted from the dominance of biological activity indicators (biofilm and bioturbation) in photo-squares, which contributed with 71.40% and 28.43% of similarity, respectively. Surface sediment presented mean contents of 0.29% gravel, 14.83% sand, and 84.89% mud, with predominant biogenic origin.

Class F was present at the central portion of the study area, where greater depths are found.

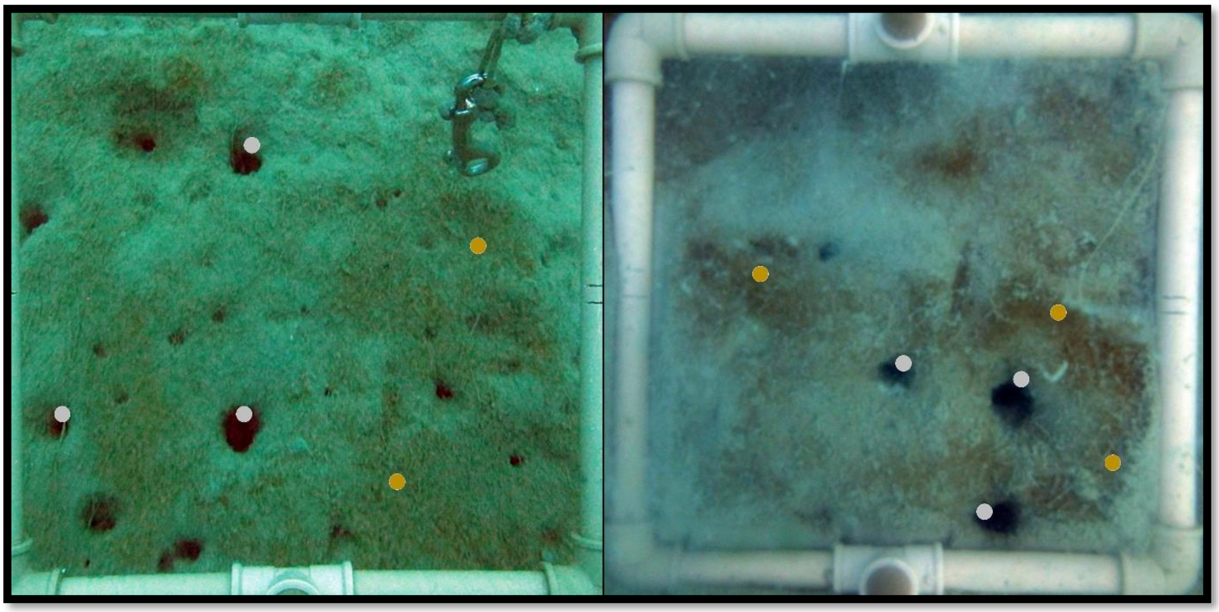

Figure 20. Examples of photo-squares obtained for Class F (predominantly muddy seafloor). Brown dots indicate biofilm; and grey dots, signs of bioturbation.

Classes G and **H** – Mangrove forest and Apicum

These classes of substrate occurred at the northeastern portion of the Maré and Madre de Deus islands, and at the northeastern portion of the study area. These regions were delimitated only during photo interpretation and were not sampled, since they are not specific to the study area. For additional information on mangroves of this area, the authors recommend the study by Queiroz and Celino (2008). The apicum ecosystem of this region has not yet been studied in detail. Information on this ecosystem is generally associated with either mangrove or coastal zone mapping studies. The authors indicate the study by Hadlich et al. (2009) for more information.

Discussion

The epibenthic communities observed generally presented good correlation with the initially mapped classes of substrates. Although the ANOSIM analysis did not separate the communities present in substrate classes D and F, they were still analyzed separately considering the accentuated dissimilarity (> 50%) and the clear environmental differences observed between them, especially regarding sediment texture. Likewise, Class E (tidal flats) showed during fieldwork that it could be comprised by either muddy or sandy sediments. Therefore, based on sediment texture, this class was subdivided into two sub-classes (E1 – sandy tidal flat, and E2 – muddy tidal flat), although the epibenthic communities found in each were the similar.

The integration of the map of substrate classes that was originally produced through photo-interpretation and field data yielded an epibenthic marine/transitional habitat map (Figure 21).

Nine epibenthic marine/transitional habitats were individualized: **Habitat A** – Reef patches, where Porifera, Zoantharia, and calcareous macroalgae predominated (total area: 9.2 km²); **Habitat B** – Intertidal rocky slabs, where soft macroalgae and Mollusca predominated (total area: 3.2 km²); **Habitat C** – Sandy substrate densely covered by soft macroalgae (total area: 8.8 km²); **Habitat D** – Predominantly sandy substrate covered by biofilm and signs of bioturbation (total area: 53.8 km²); **Habitat E1** – Sandy tidal flat covered by soft macroalgae and signs of bioturbation (total area: 8.9 km²); **Habitat E2** – Muddy tidal flat covered by soft macroalgae and signs of bioturbation (total area: 1.2 km²), **Habitat F** – Predominantly muddy substrate covered by biofilm and signs of bioturbation (total area: 54.3 km²); **Habitat G** – Mangrove forest (total area: 6.9 km²); and **Habitat H** – Apicum ecosystem (total area: 1.0 km²).

When using this habitat map, one must be aware that, in order to produce maps, delimiting lines must be drawn and that communities were defined by peaks of frequency of organisms, within the faunistic composition continuous gradient proposed by Gle'marec (1973). Therefore, sometimes there are no clear distinctions between neighboring benthic communities, but rather gradual changes in fauna composition without any discontinuities. This was clearly reflected in the present study by the superposition of epibenthic communities that were associated with various classes of substrate in the non-Metric Multidimensional Scaling analysis (nMDS), even in cases that were significantly separated by the ANOSIM test (habitats C and D).

The results obtained in the present study were generally in agreement with those from previous studies conducted in the TSB (Alves et al*.,* 2004; Pires-Vanin et al*.,* 2011; Garcia et al*.*, 2014). Previous studies focused on different aspects of epibenthic communities and did not aim to produce spatial distribution maps of these communities. Most of these studies attempted to show the relationship between the physicochemical characteristics of the environment, including substrate, and the structure of macrobenthic communities. These authors concluded that substrate geomorphology had great influence on the distribution pattern of benthic organisms, and that areas with muddy substrate presented lower species richness.

Only Cruz et al. (2009) and Valle (2013) presented attempts to map habitats. Cruz et al. (2009) mapped the occurrence of coral reefs in the TSB. The geographical distribution of their study greatly agreed with the reef patches (Habitat A) mapped in the present study. The results obtained by Cruz et al. (2009) showed that in the inner reefs of the TSB, which coincides with the study area of the present study, Porifera organisms were very frequent, the dominant coral species was *Montastraea cavernosa*, while the species *Siderastrea* sp. and the hydrocoral *Millepora alcicornis* were also abundant, in conformity with the results obtained in the present study. The community structure of epibenthic organisms of reef patches (Habitat A) presented similarity of 46.3% in the study by Cruz et al. (2009), which is close to the value found in the present study (34.34%).

The popularization of multibeam surveys over the past decade greatly increased the effectiveness of benthic marine habitat mapping. Ierodiaconou et al*.* (2007), Wilson et al*.* (2007), Le Bas and Huvenne (2009), McGonigle et al*.* (2009), Copeland et al. (2011), Lamarche et al. (2011), Rueda et al. (2011), Haris et al*.* (2012), Micallef et al*.* (2012), Hasan et al*.* (2012), Hasan et al*.* (2014), and Galparsoro et al. (2014) are examples of benthic marine habitat studies that used this method. However, this tool is still very expensive and has limited use in very shallow areas and regions that present considerable depth variability, as is the case of the present study area. Although these limitations can be compensated by the combined use of multibeam bathymetry and bathymetric LIDAR (Light Detection And Ranging), this arrangement is still beyond the reach of most researchers and governmental agencies in developing countries.

On the other hand, satellite images, which can be obtained free of cost, can be effectively used for shallow marine habitat mapping, as previously showed by several authors (Khan et al*.*, 1992; Michalek et al*.*, 1993; Ahmad and Neil, 1994; Peddle et al*.*, 1995; Matsunaga and Kayanne, 1997; Cruz et al*.*, 2009; and Dankers et al. 2011). However, although these images allow wide marine environment coverage, most of them (Landsat Thematic Mapper (TM), Enhanced Thematic Mapper – Plus (ETM +), Satellite Pour l'Observation de la Terre (SPOT), and High – Resolution Visible (HRV)) still provide limited descriptive resolution of the ecosystem (Green et al*.,* 1996; Holden and LeDrew 1998). Furthermore, the majority of satellite sensors presents a limited number of water-penetrating bands, and does not present the proper sensitivity to separate different spectral bands (Mumby and Edwards, 2002). Most satellite sensors are also limited by atmospheric conditions (cloud coverage), water turbidity, and sunlight reflected on the surface of the water.

Despite these limitations, optical sensors were considered to be an excellent tool for detailed habitat mapping in the present study area. This was partly due to intrinsic characteristics of the studied area and to the use of high-spatial-resolution images, available free of cost from Google Earth Pro. Several types of substrate found in intertidal and sublittoral areas at less than 12 m of depth were clearly visible in some of the available images.

Direct sampling techniques are also essential in habitat mapping studies, since they provide ground-truthing data regarding the real composition of the seafloor. Thus, this methodology can be considered an important stage for the validation of remote sensing data by allowing a quantitative assessment of the epibenthic environment.

The use of photo-squares was quite satisfactory not only due to the low cost of this methodology, but also for providing sufficiently accurate estimates of epibenthic species abundance. The most relevant limitations to their use are: (i) the obtained data are restricted to the water-sediment interface, which in a best-case scenario allows only inferences regarding subsurface biological activities (Fell, 1967; Owen, Sanders, and Hessler, 1967); and (ii) this methodology cannot be used under high turbidity conditions.

Finally, the main cost-related item of the present study was related to fieldwork campaigns (photo-squares, SCUBA diving, etc.), representing a total expense of approximately US$ 2,500.00. This shows the feasibility of the use of this approach in other areas where research resources are limited.

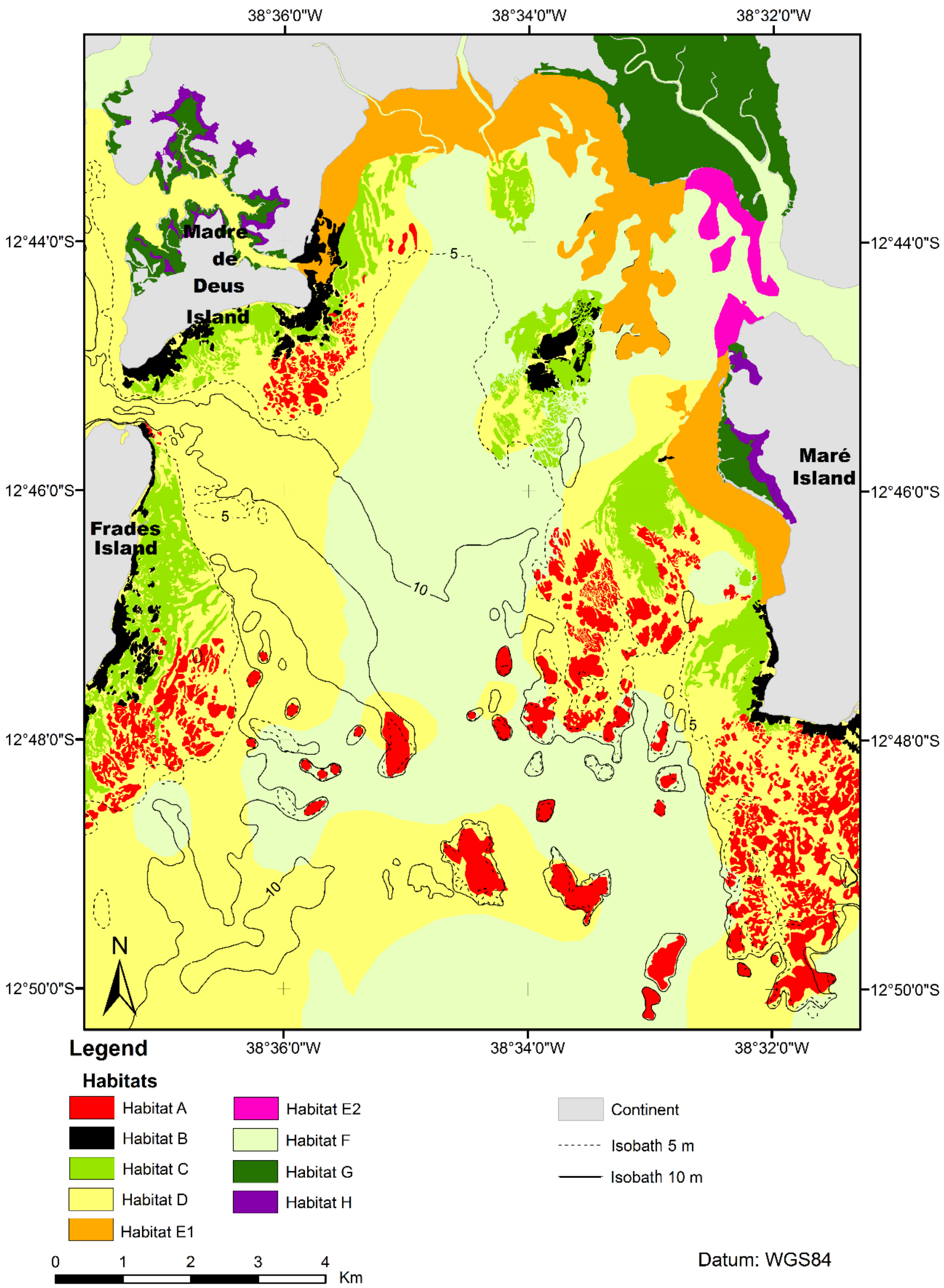

Figure 21. Epibenthic marine habitat map produced from high-resolution satellite images integrated with previous data, granulometry data, and statistical analyses. Habitat A – Reef patches, where Porifera, Zoantharia, and calcareous macroalgae predominated; Habitat B – Intertidal rocky slabs covered by soft macroalgae and Mollusca; Habitat C – Sandy substrate densely covered by soft macroalgae; Habitat D – Predominantly sandy substrate covered by biofilm and signs of bioturbation; Habitat E1 – Sandy tidal flat covered by soft macroalgae and signs of bioturbation; Habitat E2 – Muddy tidal flat covered by soft macroalgae and bioturbation; Habitat F – Muddy substrate where biofilm and signs of bioturbation predominated; Habitat G – Mangrove forests; Habitat H – Apicum.

Conclusion

The combination of the use of high-resolution satellite images, available free of cost from Google Earth Pro, and traditional field techniques (photo-squares and SCUBA diving) was a useful, effective, and low-cost strategy for creating the first epibenthic marine habitat map for the TSB. The cost for collecting data was considerably lower than if acoustic techniques were used, and the time spent was substantially shorter than what is expected of traditional benthic community studies. However, due to limitations intrinsic to the use of satellite images, the methodology used in the present study cannot be applied to deeper areas of the bay, becoming restricted to clear, shallow waters. Regardless, for the study area, the obtained results were satisfactory, allowing the identification and representation of the spatial distribution of 9 epibenthic marine habitats: Habitat A – Reef patches, where Porifera, Zoantharia, and calcareous macroalgae predominated; Habitat B – Intertidal rocky slabs covered by macroalgae and Mollusca; Habitat C – Sandy substrate densely covered by soft macroalgae; Habitat D – Predominantly sandy substrate covered by biofilm and signs of bioturbation; Habitat E1 – Sandy tidal flat covered by soft macroalgae and signs of bioturbation; Habitat E2 – Muddy tidal flat covered by soft macroalgae and bioturbation; Habitat F – Predominantly muddy substrate, where biofilm and signs of bioturbation predominated; Habitat G – Mangrove forest; and Habitat H – Apicum.

The map generated is extremely important for the management of the study area, considering that industrial activity in neighboring areas is quite expressive, and most sediment coverage was comprised by fine sediments, which favors the accumulation of organic and inorganic contaminants (i.e.: trace metals and aromatic hydrocarbons), therefore characterizing a highly vulnerable area to contamination. In addition, given the high variety of habitats in the region, this area presents one of the highest biodiversity levels in the TSB.

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References

Ahmad, W., e D. Neil., 1994. An evaluation of Landsat Thematic Mapper digital data for discriminating coral reef zonation: Heron Reef (GBR). International Journal of Remote Sensing, 15(13):2583–2597.

Alves, O.F.D.S., Manso, C.L.D.C., Absalao, R.S., de Paiva, P.C., 2004. Geoecology of sublittoral benthic communities in Todos os Santos Bay (Bahia, Brazil): biotic and sedimentological diversity. Journal of Coastal Research 2004, 1152–1155.

Araújo, J.M.C., Otero, X.L., Marques, A.G.B., Nóbrega, G.N., Silva, J.R.F., Ferreira, T.O., 2012. Selective geochemistry of iron in mangrove soils in a semiarid tropical climate: Effects of the burrowing activity of the crabs Ucides cordatus and Uca maracoani. Geo-Marine Letters, 32, 289–300.

Argollo R.M., 1999. Determinação da velocidade de sedimentação na Baía de Todos os Santos usando chumbo 210. In: Anais VI Congresso Internacional da Sociedade Brasileira de Geofísica, 1999, Rio de Janeiro, 4p.

Argollo R.M. 2001. Cronologias de sedimentos e metais pesados na Baía de Todos os Santos usando chumbo 210 e césio 137. Tese de Doutorado em Geofísica. Programa de Pós-Graduação em Geofísica, Universidade Federal da Bahia. 120 p.

Bittencourt, A.C.S.P., Ferreira, Y.A. e Di Napoli, E., 1976. Alguns aspectos na sedimentação da baía de Todos os Santos, Bahia. Revista Brasileira de Geologia, v. 6, nº4, p. 246-263,

Brown, C., Cooper, K., Meadows, W., Limpenny, D., Rees, H., 2002. Small-scale Mapping of Sea-bed Assemblages in the Eastern English Channel Using Sidescan Sonar and Remote Sampling Techniques. Estuarine Coastal and Shelf Science 54, 263–278.

Buhl-Mortensen, L., Buhl-Mortensen, P., Dolan, M. J. F., & Gonzalez-Mirelis, G., 2015. Habitat mapping as a tool for conservation and sustainable use of marine resources: some perspectives from the MAREANO programme, Norway. Journal of Sea Research, 100 p. 46-61.

Campos, R.H.S. e Dominguez, J.M.L., 2011. Shallow gas accumulations in the sediments of Todos os Santos Bay (Bahia, Brazil): origin and distribution. In: 12th International Congress of the Brazilian Geophysical Society. Rio de Janeiro.

Cirano, M., Lessa, G.C., 2007. Oceanographic characteristics of Baía De Todos os Santos, Brazil. Revista Brasileira de Geofísica. 25, 363–387.

Clarke, K. R., 1993. Non-parametric multivariate analysis of changes in community structure. Australian Journal of Ecology 18, 117–143.

Clarke, K. R. e Warwick, R. M. 1994 Change in marine communities: an approach to statistical analysis and interpretation. Natural Environment Research Council, Plymouth Marine Laboratory, Plymouth, 144 p.

Coggan, R. e Populus, 2007. What Do I Want To Map? In: Foster-smith, B. MESH Guide to Habitat Mapping, MESH Project, 2007, JNCC, Peterborough.

Copeland, A., Edinger, E., Bell, T., LeBlanc, P., Wroblewski, J., Devillers, R., 2011. Geomorphic features and benthic habitats of a subarctic fjord: Gilbert Bay, Southern Labrador, Canada, in: Harris, P.T., Baker, E.K. (Eds.), Seafloor Geomorphology as Benthic Habitat: GeoHab Atlas of Seafloor Geomorphic Features and Benthic Habitats, Elsevier, Amsterdam, The Netherlands, 2011, p. 309 – 327.

Cruz, I.C.S., Kikuchi, R.K.P., Leão, Z.M.A.N., 2009. Caracterização dos Recifes de Corais da Área de Preservação Ambiental da Baía de Todos os Santos para Fins de Manejo, Bahia, Brazil. Revista Gestão Costeira Integrada. 9, 3–23.

Dankers, N., van Duin, W., Baptist, M., Dijkman, E., Cremer, J., 2011. The Wadden Sea in the Netherlands: ecotopes in a World Heritage barrier island system, in: Harris, P.T., Baker, E.K. (Eds.), Seafloor Geomorphology as Benthic Habitat: GeoHab Atlas of Seafloor Geomorphic Features and Benthic Habitats, Elsevier, Amsterdam, The Netherlands, 2011, p. 213 - 226.

Dominguez, J.M.L. e Bittencourt, A.C.S.P., 2009. Geologia. In: Vanessa Hatje e Jailson Bittencourt de Andrade (Orgs). Baía de Todos os Santos: Aspectos oceanográficos. Salvador: Edufba. p. 29-66.

Dominguez, J.M.L., Nunes, A.S., Rebouças, R.C., Silva, R.P da, Freire, A.F.M., Poggio, C.A, 2012. Plataforma continental. In: Silva, J., Correia, S., n.d. Geologia da Bahia: pesquisa e atualização. Salvador: CBPM. p. 427-96.

Fell, H. B., 1967. Biological applications of sea-floor photography. In J. B. Hersey (Ed.), Deep-Sea Photography (pp. 207–221). Baltimore: The Johns Hopkins Press.

Findlay, R.H.; Trexler, M.D. e White, D.C., 1990. Response of a benthic microbial community to biotic disturbance. Marine Ecology Progress Series, 62, p. 135-148.

Friedrichs, M., Leipe, T., Peine, F., Graf, G., 2009. Impact of macrozoobenthic structures on near-bed sediment fluxes. Journal of Marine Systems, 75, 336–347.

Galparsoro, I., Germán, J., Menchaca, I., Quincoces, I., 2014. Benthic habitat mapping on the Basque continental shelf (SE Bay of Biscay) and its application to the European Marine Strategy Framework Directive. Journal of Sea Research, 100, 70–76.

Garcia, K.S., Emanuel, L., Acacio, M., Falc, O., Cordeiro, O.M., Edmund, J., Maddock, L., Bet, M., Silva, F., 2014. Análise da macrofauna bentônica da região nordeste da baía de todos os santos, bahia. Caderno de Geociências, 11, 121–134.

Gle´marec, M., 1973. The benthic communities of the European North Atlantic Shelf. Oceanography and Marine Biology Annual Review 11, 263–289.

Green, E. P., Mumby, P. J., Edwards, A. J., e Clark, C. D., 1996. A review of remote sensing for tropical coastal resources assessment and management. Coastal Management, 24, 1– 40.

Greene, H. G., Bizzarro, J. J., O'Connell, V. M., e Brylinsky, C. K., 2007. Construction of digital potential marine benthic habitat maps using a coded classification scheme and its application. Mapping the seafloor for habitat characterization: Geological Association of Canada Special Paper, 47, 141-155.

Hadlich, G. M., Ucha, J. M., de Oliveira, T. L., 2009. Distribuição de apicuns e de manguezais na Baía de Todos os Santos, Bahia, Brasil. Anais do XIV Simpósio Brasileiro de Sensoriamento Remoto, 1, 4607-4614.

Hall, S.J., 1994. Physical disturbance and marine benthic communities: life in unconsolidated sediments. Oceanography and marine biology. Ann. Rev.,32, p. 179-239.

Haris, K., Chakraborty, B., Ingole, B., Menezes, A., e Srivastava, R., 2012. Seabed habitat mapping employing single and multi-beam backscatter data: A case study from the western continental shelf of India. Continental Shelf Research, 48, 40-49.

Harris, P. T. e Baker, E. K., 2011. Why Map Benthic Habitats? In: Harris, P.T. e Baker, E. K. (Eds.), Seafloor Geomorphology as Benthic Habitat: GeoHab Atlas of Seafloor Geomorphic Features and Benthic Habitats, Elsevier, Amsterdam, 2011 (Chapter 1).

Hasan, R. C., Ierodiaconou, D., e Monk, J., 2012. Evaluation of four supervised learning methods for benthic habitat mapping using backscatter from multi-beam sonar. Remote Sensing, 4(11), 3427-3443.

Hasan, R. C., Ierodiaconou, D., Laurenson, L., & Schimel, A., 2014. Integrating multibeam backscatter angular response, mosaic and bathymetry data for benthic habitat mapping. Plos one, 9(5).

Hatje, V., Barros, F.C.R., Figueiredo, D.G. e Santos, V.L.C.S., 2006. Trace metal contamination and benthic assemblages in Subaé estuarine system, Brazil. Marine Pollution Bulletin, 52(8): 969-977.

Hatje, V., Bícego, M. C., Carvalho, G. C., de Andrade, J. B., 2009. Contaminação Química. In: Hatje, V., e de Andrade, J. B. (Org.). Baía de Todos os Santos: aspectos oceanográficos. Salvador: EDUFBA, 2009. p. 245-297.

Henriques, V., Guerra, M. T., Mendes, B., Gaudêncio, M. J., & Fonseca, P., 2015. Benthic habitat mapping in a Portuguese marine protected area using EUNIS: an integrated approach. Journal of Sea Research, 100, p. 77-90.

Holden, H., e LeDrew, E., 1998. The scientific issues surrounding remote detection of submerged coral ecosystems. Progress in Physical Geography, 22, 122– 190.

Hunt, B., Vincent, A.C.J., 2006. Scale and sustainability of marine bioprospecting for pharmaceuticals. Ambio 35, 57–64.

IBGE – Instituto Brasileiro de Geografia e Estatística, 2016 – Disponível em: ftp://ftp.ibge.gov.br/Estimativas_de_Populacao/Estimativas_2016/estimativa_dou_2016_20160913.pdf. Acesso em: 11 de janeiro de 2017.

Ierodiaconou, D., Laurenson, L., Burq, S., e Reston, M., 2007. Marine benthic habitat mapping using Multibeam data, georeferencedvideo and image classification techniques in Victoria, Australia. Journal of spatial science, 52(1), 93-104

Khan, M. A., Fadlallah, Y. H., e Al-Hinai, K. G., 1992. Thematic mapping of subtidal coastal habitats in the western Arabian Gulf using Landsat TM data—Abu Ali Bay, Saudi Arabia. International Journal of Remote Sensing, 13(4), 605-614.

Kinoshita, K., Wada, M., Kogure, K., Furota, T., 2003. Mud shrimp burrows as dynamic traps and processors of tidal-flat materials. Marine Ecology Progress Series, 247, 159–164.

Kohler, K.E., Gill, S.M., 2006. Coral Point Count with Excel extensions (CPCe): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology. Computer and Geosciences. 32, 1259–1269.

LaFrance, M., King, J. W., Oakley, B. A., & Pratt, S., 2014. A comparison of top-down and bottom-up approaches to benthic habitat mapping to inform offshore wind energy development. Continental Shelf Research, 83, p. 24-44.

Lamarche, G., Rowden, A.A., Mountjoy, J., Lucieer, V., Verdier, A.L., 2011. The Cook Strait Canyon, New Zealand: a large bedrock canyon system in a tectonically active environment, in: Harris, P.T., Baker, E.K. (Eds.), Seafloor Geomorphology as Benthic Habitat: GeoHab Atlas of Seafloor Geomorphic Features and Benthic Habitats, Elsevier, Amsterdam, The Netherlands, 2011, p. 727 – 737.

Lana, P. D. C., Camargo, M. D., Brogim, R. A., e Isaac, V. J., 1996. O bentos da costa brasileira: avaliação crítica e levantamento bibliográfico (1858-1996). FEMAR, Rio de Janeiro. Disponível em: <http://www.mma.gov.br/estruturas/revizee/_arquivos/bentos>. Acesso em: 30 de abril de 2015.

Le Bas, T. P., e Huvenne, V. A. I., 2009. Acquisition and processing of backscatter data for habitat mapping–comparison of multibeam and sidescan systems. Applied Acoustics, 70(10), 1248-1257.

Lessa, G.C., Dominguez, J.M.L., Bittencourt, A.C.S.P., Brichta, A., 2001. The Tides and Tidal Circulation of Todos os Santos Bay, Northeast Brazil: a general characterization. In: Anais da Academia Brasileira de Ciências, v.73, p. 245-61.

Lessa, G., Dias, K., 2009. Distribuição espacial das litofácies de fundo da Baía de Todos os Santos. Quaternary and Environmental Geosciences. 1, 84–97.

Levins, R. E.; Lewontin, R., 1980. Dialectics and Reductionism in Ecology, In: Keller, D. R. and Golley, F.B. The Philosophy of Ecology: From Science to Synthesis. Athens: The University of Georgia Press, p. 218-225.

Lund, K., e Wilbur, A. R., 2007. Habitat classification feasibility study for coastal and marine environments in Massachusetts. Massachusetts Office of Coastal Zone Management, Boston, 58, 31p.

Marins, B. V., Brasileiro, P. S., de Barros Barreto, M. B., de Castro Nunes, J. M., Yoneshigue-Valentin, Y., e Amado Filho, G. M., 2008. Subtidal benthic marine algae of the Todos os Santos bay, Bahia State, Brazil. Oecologia Brasiliensis, 12(2), 5.

Martins, L.K.P., Nascimento, I.A., Fillmann, G., King, R., Evangelista, A.J.A., Reandman, J.W. e Depledge, M.H., 2005 - Lysosomal responses as a diagnostic tool for the detection of chronic petroleum pollution at Todos os Santos Bay, Brazil. Environmental Research, 99(3):387-396.

Markert, E., Holler, P., Kröncke, I., & Bartholomä, A., 2013. Benthic habitat mapping of sorted bedforms using hydroacoustic and ground-truthing methods in a coastal area of the German Bight/North Sea. Estuarine, Coastal and Shelf Science, 129, p. 94-104.

Matsunaga, T., e Kayanne, H., 1997. Observation of coral reefs on Ishigaki island, Japan, using Landsat TM images and aerial photographs. Proceedings of the Fourth International Conference on Remote Sensing for Marine and Coastal Environments, 17–19 March, Orlando, Florida, 1:657–666.

McGonigle, C., Brown, C., Quinn, R., e Grabowski, J., 2009. Evaluation of image-based multibeam sonar backscatter classification for benthic habitat discrimination and mapping at Stanton Banks, UK. Estuarine, Coastal and Shelf Science, 81(3), 423-437.

Meysman, F.J.R., Middelburg, J.J., Heip, C.H.R., 2006. Bioturbation: a fresh look at Darwin's last idea. Trends in Ecology and Evolution, [S.I], v. 21, nº12, p.688-95.

Micallef, A., Le Bas, T. P., Huvenne, V. A., Blondel, P., Hühnerbach, V., e Deidun, A., 2012. A multi-method approach for benthic habitat mapping of shallow coastal áreas with high-resolution multibeam data. Continental Shelf Research, 39, 14-26.

Michalek, J. L., Wagner, T. W., Luczkovich, J. J., e Stoffle, R. W., 1993. Multispectral change vector analysis for monitoring coastal marine environments. Photogrammetric Engineering e Remote Sensing, 59(3):381–384.

Mumby, P. J., e Edwards, A. J., 2002. Mapping marine environments with IKONOS imagery: enhanced spatial resolution can deliver greater thematic accuracy. Remote sensing of Environment, 82(2), 248-257.

Nanami, A.; Saito, H.; Akita, T.; Motomatsu, K.; Kuwahar, H., 2005. Spatial Distribution and Assemblage Structure of Macrobenthic Invertebrates in a Brackish Lake in Relation to Environmental Variable. Estuarine, Coastal and Shelf Science, v. 63, p. 167-176.

Owen, D. M. Sanders, H. L., e Hesseler, R. R., 1967. Bottom photography as a tool for estimating benthic populations. In: J. B. Hersey (Ed.) Deep-Sea Photography, (pp. 229–234). The Johns Hopkins Press.

Peddle, D. R., LeDrew, E. F., e Holden, H. M., 1995. Spectral mixture analysis of coral reef abundance from satellite imagery and in situ ocean spectra, Savusavu Bay, Fiji. In: Proceedings of the Third Thematic Conference on Remote Sensing for Marine and Coastal Environments (Vol. 2, pp. 563-575).

Pires-Vanin, A.M.S., Muniz, P., de Léo, F.C., 2011. Benthic macrofauna structure in the northeast area of todos os santos bay, bahia state, Brazil: Patterns of spatial and seasonal distribution. Brazilian Journal of Oceanography, 59, 27–42.

Posey, M.H., 1987. Influence of relative mobilities on the composition of benthic communities. Marine Ecology Progress Series, 39, p. 99-104.

Queiroz, A.F.S. e Celino, J.J., 2008. Manguezais e ecossistemas estuarinos da Baía de Todos os Santos. In: Queiroz, A.F.S. e Celino, J. J. (Org.). Avaliação de ambientes na Baía de Todos os Santos: Aspectos geoquímicos, geofísicos e biológicos. Salvador: RECUPETRO-PROAMB, 2008. p. 39-58.

Roff, J.C., Taylor, M.E., Laughren, J., 2003. Geophysical approaches to the classification, delineation and monitoring of marine habitats and their communities. Aquatic Conservation: Marine and Freshwater Ecosystems, 13: 77–90.

Rueda, J.L., Díaz-del-Río, V., Sayago-Gil, M., López, N., Fernández L.M., Vázquez J.T., 2011. Fluid venting through the seabed in the Gulf of Cadiz (SE Atlantic Ocean, western Iberian Peninsula): geomorphic features, habitats and associated fauna, in: Harris, P.T., e Baker E.K. (Eds.), Seafloor Geomorphology as Benthic Habitat: GeoHab Atlas of Seafloor Geomorphic Features and Benthic Habitats, Elsevier, Amsterdam, 2011, p. 831 – 841.

Soares, L.S.H., Salles A.C.R., Lopez, J.P., Muto, E.Y., Giannini, R., 2009. Pesca e Produção Pesqueira. In: Hatje, V., e de Andrade, J. B. (Org.). Baía de Todos os Santos: aspectos oceanográficos. Salvador: EDUFBA, 2009. p. 159-206.

Tavares, T.M., Beretta, M. e Costa M.C.,1999. Ratio of DDT/DDE in the All Saints Bay, Brazil and its Use in Environmental Management. Chemosphere, 38(6): 1445-1452.

Valle, M. M., 2013. História do preenchimento sedimentar da porção nordeste da Baía de Todos os Santos, Bahia, Brasil e sua influência sobre a evolução dos hábitats bentônicos. Monografia apresentada ao Curso de Oceanografia, Instituto de Geociências, Universidade Federal da Bahia. Salvador, Bahia. 65 p.

Venturini, N. e Tommasi, L.R., 2004 – Polycyclic Aromatic Hydrocarbons and Changes in the Trophic Structure of Polychaete Assemblages in Sediments of Todos os Santos Bay, Northeastern, Brazil. Marine Pollution Bulletin, 48(1-2): 97-107.

Vilas Boas, G.S. e Bittencourt, A.C.S.P., 1979. Química e mineralogia da fração argilosa dos sedimentos do fundo da baía de Todos os Santos. Revista Brasileira de Geologia, v.9, nº3, p.159-68.

Xavier, A. G. (2002) Análise hidrodinâmica da Baía de Todos os Santos. Tese de doutorado, Programa de Pós-Graduação em Engenharia, Universidade Federal do Rio de Janeiro, 222 p.

Wallner-Kersanach, M., Theede, H., Eversberg, U. e Lobo, S., 2000. Accumulation and Elimination of Trace Metals in a Transplantation Experiment with Crassostrea rhizophorae. Archives of Environmental Contamination and Toxicology, 38(1):40-45.

Wilson, M. F., O'Connell, B., Brown, C., Guinan, J. C., e Grehan, A. J., 2007. Multiscale terrain analysis of multibeam bathymetry data for habitat mapping on the continental slope. Marine Geodesy, 30(1-2), 3-35.

Wolgemuth KM, Burnett WC, Moura PL., 1981. Oceanography and suspended material in Todos os Santos Bay. Revista Brasileira de Geociências, 11(3): 172-178.

CAPÍTULO 3
CONCLUSÕES

1. CONCLUSÃO

A combinação do uso de imagens de satélite de alta resolução com imagens fotográficas submarinas obtidas por meio de mergulho autônomo provou ser uma técnica útil, eficaz e de baixo custo para a confecção do primeiro mapa de habitats marinhos epibentônicos para a BTS. Os custos com os levantamentos foram consideravelmente menores, quando comparados à utilização de técnicas acústicas, e o tempo despendido foi substancialmente inferior ao das técnicas tradicionais de estudos de comunidades bentônicas. Entretanto, devido às limitações intrínsecas à utilização de imagens de satélite, a metodologia utilizada não pode ser estendida para as regiões mais profundas da baía, restringindo-se a águas claras e de pouca profundidade. De todo modo, para a área de estudo, os resultados obtidos foram satisfatórios, possibilitando a identificação e representação da distribuição espacial de 9 habitats marinhos epibentônicos: Habitat A - Bancos recifais com predomínio de Porifera, Zoantharia e Calcareous macroalgae; Habitat B – Lajes rochosas intermareais cobertas por macroalgas e Mollusca; Habitat C – Substrato arenoso com densa cobertura de Soft macroalgae; Habitat D – Substrato predominantemente arenoso recoberto por Biofilm e marcas de Bioturbation; Habitat E1 – Planície de maré arenosa com cobertura de Soft macroalgae e marcas de Bioturbation; Habitat E2 – Planície de maré lamosa com cobertura de Soft macroalgae e Bioturbation; Habitat F – Substrato predominantemente lamoso com predomínio de Biofilm e marcas de Bioturbation; Habitat G – Manguezais; e Habitat H – Apicuns. O mapa gerado é de extrema importância para a área estudada, uma vez que a atividade industrial é expressiva nas suas cercanias, e a maior do sedimento apresenta uma textura fina, o que acaba favorecendo a acumulação de contaminantes orgânicos e inorgânicos (ex: metais traços e hidrocarbonetos aromáticos), constituindo-se, portanto, em uma região altamente vulnerável à contaminação.

APÊNDICE A – JUSTIFICATIVA DA PARTICIPAÇÃO DOS CO-AUTORES

1. PROF. DR. **JOSÉ MARIA LANDIM DOMINGUEZ**

Orientador do aluno, forneceu diretrizes para que o trabalho fosse concluído, acompanhando desde o princípio o desenvolvimento da pesquisa, tendo participação fundamental.

2. DR. **IVAN CARDOSO LEMOS JÚNIOR**

O biólogo possui amplo conhecimento em bioestatísca e contribuiu significativamente nas análises estatísticas e interpretação destas, enriquecendo o trabalho.

3. PROFa. DRa. **CARLA MARIA MENEGOLA DA SILVA**

A bióloga possui amplo conhecimento em taxonomia de esponjas e espécies bentônicas, auxiliando na identificação destes organismos, etapa que precede as análises estatísticas.

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