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Methodological proposal for characterization of marine geodiversity in the South Atlantic: Vitória-Trindade Ridge and adjacent areas, Southeast of Brazil*

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ABSTRACT

Knowledge of marine geodiversity aids in the understanding of geological processes that operate in the marine domain. These processes are responsible for the creation of landscapes, interference in ocean current patterns and sediment deposition, formation of mineral deposits, triggering of geological hazards and biodiversity development, among other aspects. Marine geodiversity surveys enable an integrated perspective of the dynamics and geological processes occurring in the continental margins and sea basins. They can provide essential information regarding the suitability and limitations of this region during considerations of numerous possibilities for use.

This study was aimed at developing a regional-scale model for characterizing marine geodiversity in the Vitória–Trindade Volcanic Seamount Ridge and its adjacent marine areas in the South Atlantic off the coast of southeastern Brazil. The adopted methodology involved defining marine geodiversity compartments in a geographic information system environment by integrating and analyzing spatial variables obtained from bathymetric, geological, and geophysical data as well as by using information available from the literature, government databases, and research institutions. Five representative aspects of geodiversity in the study area were defined, namely, scientific, environmental, economic, academic, and geotouristic characteristics.

From this analysis, 13 key areas with peculiar aspects of geodiversity, geoheritage, and potential use were selected for further analyses. For the selected areas, records of scientific and educational interest about the geological history of the opening of the South Atlantic Ocean and formation of the Brazilian continental margin were reviewed and potential areas of use aimed at geotourism and mineral exploration were examined. Restrictions on use related to geologic hazards and anthropogenic actions as well as the legal, technological, and financial aspects arising from the occupation of these spaces were discussed.

The information obtained aims to support the actions of the Brazilian government for marine spatial planning with regard to the exploitation of resources and geoconservation of the unique aspects of the geological history of Brazil and the most susceptible habitats. This work also serves as an orientation framework for future surveys of geodiversity in other marine regions.

Keywords: Geoheritage, Marine landscapes, Geographic information system, Land management, Brazilian Exclusive Economic Zone.

RESUMO

Proposta Metodológica para caracterização da geodiversidade marinha no Atlântico Sul: Cadeia Vitória-Trindade e áreas adjacentes, sudeste do Brasil.

O conhecimento de geodiversidade marinha torna possível a compreensão dos processos geológicos que atuam no domínio marinho, responsáveis por gerar paisagens, interferir nos padrões de circulação das correntes oceânicas e da deposição sedimentar, formar depósitos minerais, desencadear fenômenos causadores do risco geológico e subsidiar ao desenvolvimento

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da biodiversidade, dentre outros aspectos. Levantamentos da geodiversidade marinha possibilitam uma visão integrada das dinâmicas e processos geológicos ocorrentes nas margens continentais e bacias oceânicas, podendo oferecer informações fundamentais quanto às adequações e limitações desse meio perante as múltiplas possibilidades de uso. O presente trabalho teve como objetivo desenvolver um modelo, em escala regional, para caracterização da geodiversidade marinha, tendo como área-piloto a Cadeia de Montes Vulcânicos Submarinos de Vitória–Trindade e áreas adjacentes, situada no Atlântico Sul, sudeste do Brasil. A metodologia adotada compreendeu a definição de compartimentos da geodiversidade marinha, em ambiente de sistema de informação geográfica, através da integração e análise de variáveis espaciais resultantes de dados batimétricos, geológicos, geofísicos e de uso e ocupação, disponíveis na literatura e em bancos de dados governamentais e de instituição de pesquisas. Foram definidos 5 compartimentos representativos da geodiversidade da área de estudo, os quais foram atribuídos valores científicos, ambientais, econômicos, educativos e geoturísticos. Dessa análise, resultou a seleção de 13 áreas-chaves representativas de aspectos peculiares da geodiversidade marinha e do patrimônio geológico e potencial de uso a elas associado. As áreas selecionadas incluem registros de interesse científico e educativo sobre a história geológica da abertura do Oceano Atlântico Sul e formação da Margem Continental Brasileira, áreas potenciais de uso voltadas ao geoturismo e aproveitamento mineral. Foram abordadas restrições ao uso relacionado ao risco geológico; ações antrópicas; aspectos legais, tecnológicos e financeiros decorrentes da ocupação desses espaços. As informações obtidas visam subsidiar as ações governamentais brasileiras para o ordenamento do território marinho quanto ao aproveitamento de seus recursos e geoconservação dos aspectos singulares da história geológica brasileira e dos habitats mais suscetíveis. Constitui dessa forma um orientativo para futuros levantamentos da geodiversidade em regiões marinhas.

Palavras-chaves: *Patrimônio geológico, Paisagens marinhas, Sistema de Informação Geográfica, Planejamento territorial, Zona Econômica Exclusiva Brasileira.*

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1. Introduction

1.1. Framework

The term "geodiversity" emerged in the 1990s as a counterpart to "biodiversity," and it defines the abiotic component of nature (Gray, 2004, 2008). Over the following years, the concept of geodiversity has been increasingly used, which has helped it to take on the same importance as the concept of biodiversity. However, in the marine realm, there have been few studies related to geoheritage and geoconservation. Relevant research to date has been restricted to coastal areas and submerged portions of oceanic islands and the adjacent seafloor (Nunes *et al.*, 2007; Felton, 2010; Booth & Brayson, 2011; Kaskela *et al.*, 2012; Lima *et al.*, 2014).

The term marine geodiversity refers to the abiotic variety of nature in the seabed; this abiotic variety is a result of geological processes such as tectonism, magmatic volcanism, sedimentary deposition, and modification by marine geomorphological processes.

Studies on geodiversity focusing directly on the seabed are relatively recent; such studies have been conducted in the Baltic Sea, Gulf of Finland, and in seas off the United Kingdom. In general, such studies are intended to document relationships between biodiversity and geodiversity and to identify areas where both marine biotic and abiotic aspects have to be protected (Rovere *et al.*, 2010; Gordon & Barron, 2011; Burek *et al.*, 2012; Brooks *et al.*, 2012).

1.1.1. *Geodiversity approach in the Brazilian territory*

In Brazil, the application of the concepts of geodiversity and geoheritage and the corresponding methodology is in the consolidation phase. Studies that have been conducted in this region have focused on the physical environment of the continental, coastal, and island portions in order to promote territorial management policies by government agencies and support the work of research institutions and researchers dedicated to geoheritage, geoconservation, and geotourism issues (Schmitt & Mansur, 2001; Nascimento *et al.*, 2008; Mansur & Carvalho, 2011).

The most relevant initiatives are as follows:

- registration of geological sites at the worldwide level by the Brazilian Commission on Geological and Palaeobiological Sites (*Comissão Brasileira dos Sítios Geológicos e Paleobiológicos–SIGEP*) (sigep.cprm.gov.br);
- Geological Paths Project of Rio de Janeiro State (*Projeto Caminhos Geológicos*), which works for the promotion and preservation of geoheritage through educational signboards (www.caminhosgeologicos.rj.gov.br);
- Geological and Paleontological Site Project of Paraná State (*Projeto Sítio Geológico e Paleontológico do Paraná*) (www.mineropar.pr.gov.br);
- Geological Monuments Project of São Paulo State (*Projeto Monumentos Geológicos do Estado de São Paulo*) (www.igeo logico.sp.gov.br);
- Geoparks Project *(Projeto Geoparques*), which is conducted by the Geological Survey of Brazil (*Serviço Geológico do Brasil/Companhia de Pesquisa de Recursos Minerais–CPRM*) and aims to describe and identify areas with potential for future geoparks in the Brazilian territory (www.cprm.gov.br); and

- Geodiversity Surveying Program (*Programa de Levantamento da Geodiversidade*), which is conducted by the CPRM in all Brazilian states and border areas (www.cprm.gov.br).

In Brazil, Maia *et al.* (2012) were the first to propose an approach based on the "marine geodiversity" theme. In their work, a preliminary view of the physiographic subdivisions and the geological characteristics of the Vitória–Trindade Volcanic Seamount Ridge and its adjacent region were presented. In a study on the geoconservation of Trindade Island, Pires *et al.* (2013) stressed the importance of the island and its significant heritage value because of the rarity of the rocks and volcanic-magmatic structures present there.

1.2. Objective

This study aims to characterize the marine geodiversity in the Vitória - Trindade Ridge and adjacent marine areas at a regional scale (1:2,500,000) by means of geoprocessing techniques made possible by a Geographic Information System (GIS). Key areas with aspects relevant to geodiversity are first identified, and then analyses of the main geoheritage aspects and their potential for use are presented.

2. Study area

2.1. Location

The study area extends to about 740,000 km^2, and it covers the Vitória - Trindade Ridge and other physiographic features in the 200 nautical miles of the Brazilian Exclusive Economic Zone (EEZ) and an area proposed by the Brazilian government for the expansion of the Brazilian Legal Continental Shelf Brazilian. The Vitória - Trindade Ridge is located in the South Atlantic between the latitudes of 20° 29′ – 20° 32′ S and the longitudes of 29° 17′ – 29° 21′ W; it lies along the coast of Espírito Santo State, Brazil (Figure 1).

2.2. Vitória–Trindade Ridge

The Vitória - Trindade Ridge consists of approximately 30 seamounts and submarine banks (Besnard bank, Champlain seamount, Vitória seamount, Congress bank, Montague seamount, Jaseur seamount, Colúmbia bank, Davis bank, Dogaressa bank, Colúmbia sea-mount, and other unnamed elevations) that are morphologically recognized as volcanic buildings, and at least 17 are submerged volcanoes with heights exceeding 2,500 m (Motoky *et al.*, 2012). The outcropping portion is located at the western end of the ridge about 600 m above sea level; this area corresponds to Trindade Island (10.2 km^2) and the Martin Vaz Archipelago (0.3 km^2).

Some studies indicate that the origin of the Vitória - Trindade Ridge was associated with Cenozoic tectonomagmatic activities that occurred during South American plate displacement under the action of a mantle plume that is currently located under Trindade Island and the Martin Vaz Archipelago (Thomaz Filho & Rodrigues, 1999; Skolotnev *et al.*, 2011). Alves *et al.* (2006) relates the Vitória - Trindade Ridge origin to the Vitória–Trindade Fracture Zone, through which magma from the mantle might have ascended to the surface.

3. Methodological proposal

The Brazilian Continental Margin (BCM) and adjacent areas have been surveyed by the Brazilian Government for the purpose of extending maritime legal domains. The existing studies are generally on a regional scale and pertain to a specific theme, mainly related to the oil industry in the areas of marginal sedimentary basins. Hence, little is known about the Brazilian Ocean Basins (BOB).

In the absence of systematic information on the physical environment in the study area, a proposal was made to construct a regional-scale marine geodiversity characterization model through bibliographic compilations and integration of environmental, bathymetric, geological, and geophysical data including data used in GISs. In order to exemplify the geodiversity of the study area, which ranges from shallow portions of the BCM to the ultra-deep water regions of the BOB, key areas that represent this geodiversity, geoheritage, and associated potential use were evaluated.

This work proposal was divided into five main stages, as shown in Figure 2, and the stages were as follows: (1) literature review and general data acquisition; (2) organization of data in the GIS; (3) generation of products and auxiliary analyses; (4) definition of marine geodiversity compartments; and (5) valuation of geodiversity and selection of key areas.

3.1. Literature review and data acquisition

Databases from government and research institutions as well as information available on the internet were consulted (see Supporting Information). The acquired data were derived from the main survey programs already carried out by the Brazilian Government in the Brazilian Legal Continental Shelf area over the last 40 years; these programs included REMAC (*Reconhecimento Global da Margem Continental Brasileira* [Global Recognition of Brazilian Continental Margin]), LEPLAC (*Plano de Levantamento da Plataforma Continental Brasileira* [Surveying Plan of the Brazilian Continental Shelf]), and REMPLAC (*Programa de Avaliação da Potencialidade Mineral da Plataforma Continental Jurídica Brasileira* [Program for Evaluating the Mineral Potential of the Brazilian Legal Continental Shelf]).

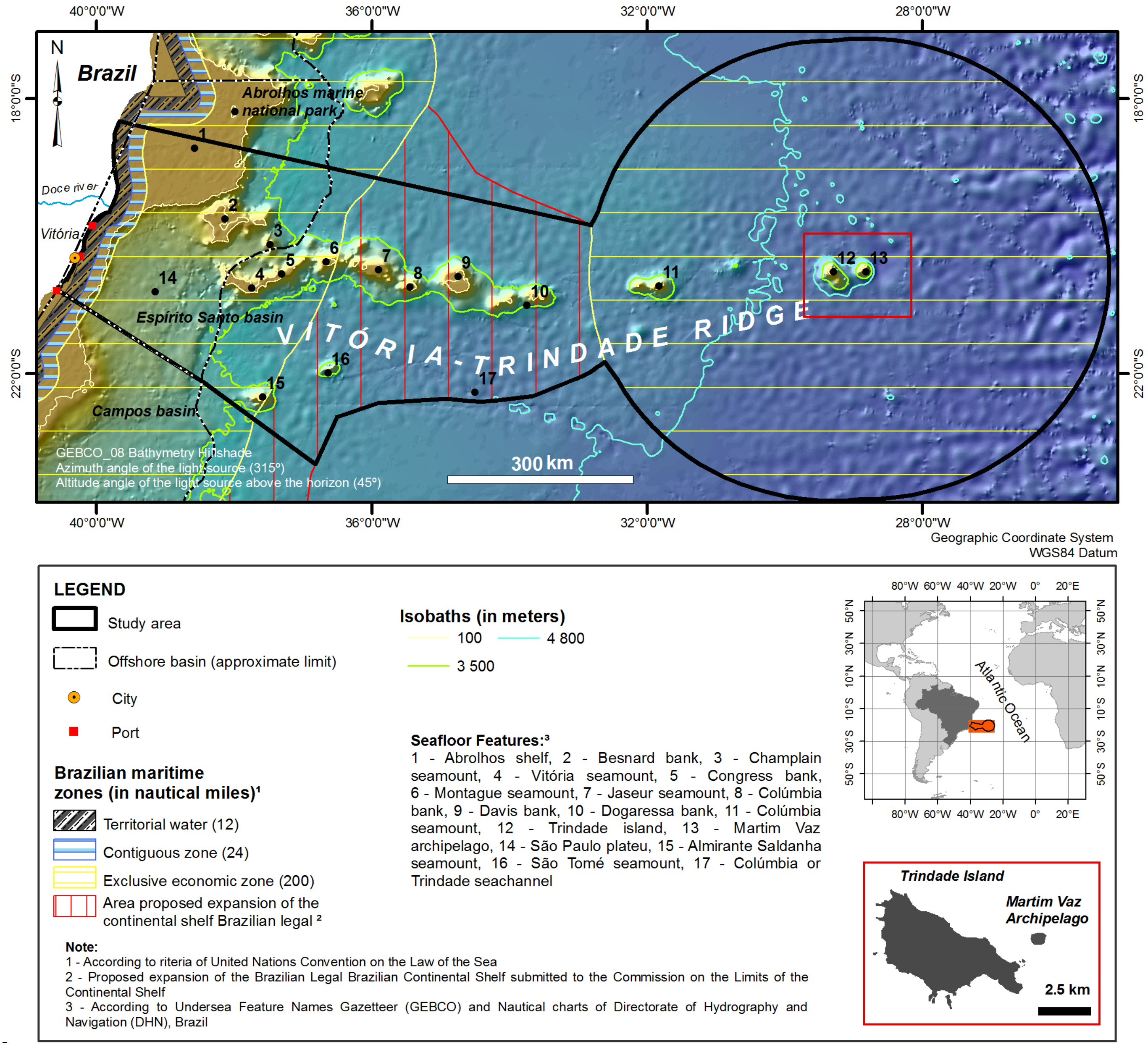


Figure 1 - Location of the study area. The names of locations are from Undersea Feature Names Gazetteer and Nautical Charts of the Directorate of Hydrography and Navigation (DHN), Brazil.

Figura 1 - Localização da área de estudo. Topônimos retirados das Cartas náuticas da Diretoria de Hidrologia e Navegação (DHN).

3.2. Organization of data in the GIS

Since data from various sources and corresponding to different acquisition dates, formats, scales, and cartographic projections were used, systematization of data procedures became necessary for the subsequent organization of the information in the GIS. The GIS organization and other functions were performed using ESRI ArcDesktop GIS (ArcMap, ArcScene, 3D Analyst Tools, Data Management Tools, Spatial Analyst) and Global Mapper (Version 12) programs.

The map projection used was the Geographic Coordinate Projections System and Universal Transverse Mercator (World Geodesic System 1984-WGS84 datum), which has a central meridian with a source latitude of 0° and a source longitude origin of 33°W corresponding to Greenwich. The 1:2,500,000 scale was chosen for data integration since it allows for the analysis of the information within the GEBCO_08 data spatial resolution (see Supporting Information).

3.3. Generation of products and auxiliary analyses

In the GIS environment, geoprocessing techniques were applied and spatial data analysis was performed (e.g., information overlays, classifications, topological research, data interpolations via ArcGIS/Spatial Analyst Tools) on the acquired information to generate auxiliary

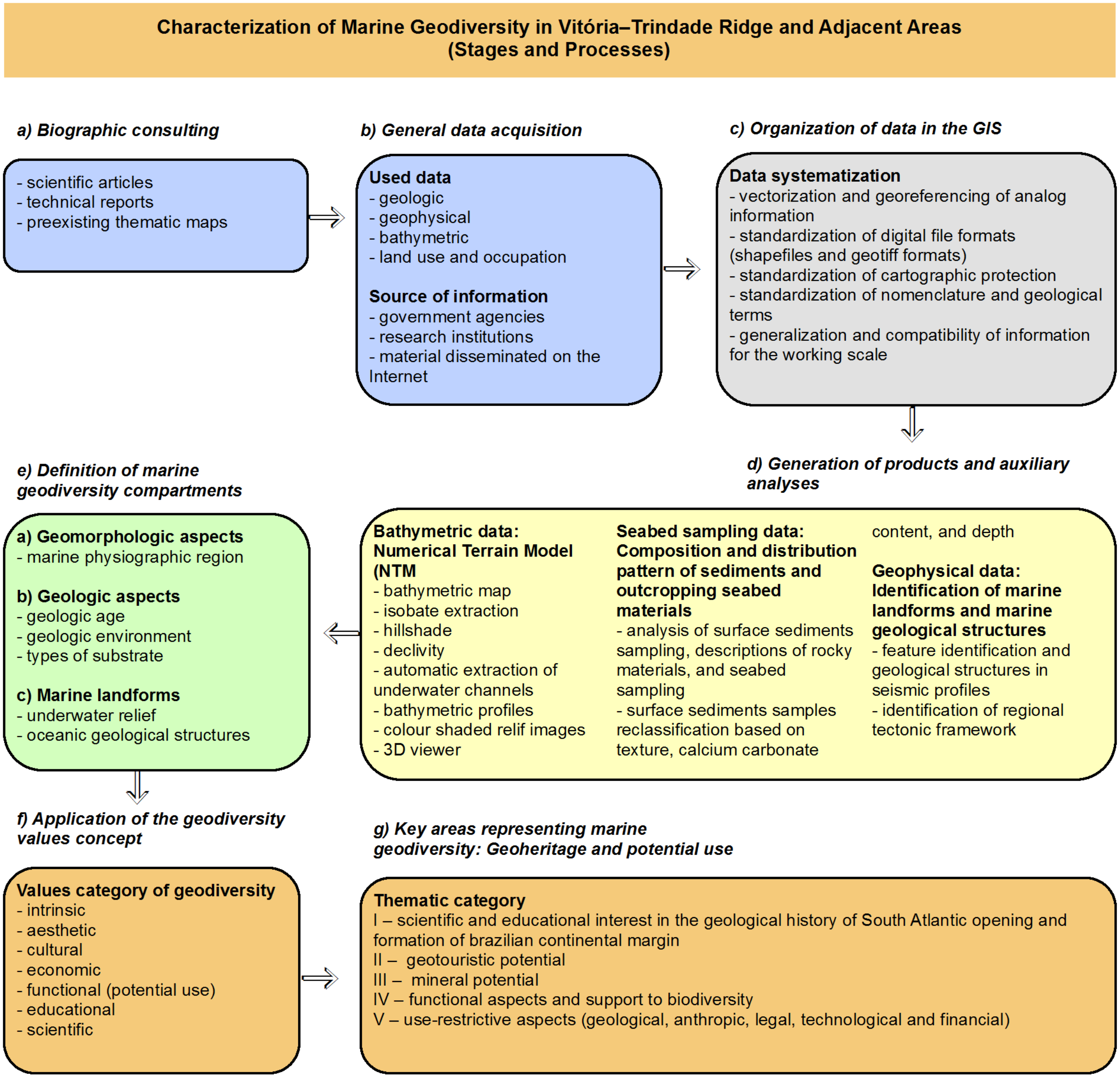


Figure 2 - Methodological procedure adopted in drawing up the sea geodiversity characterization model of the study area. Procedure stages: 1) bibliographic consultation and data acquisition (blue); 2) data organization in the geographic information system (GIS) (gray); 3) generation of products and auxiliary analyses (yellow); 4) definition of sea geodiversity compartments (green); and 5) valuation of geodiversity and selection of key areas (brown).

Figura 2 - Procedimento metodológico adotados na elaboração do modelo para caracterização da geodiversidade marinha da área de estudo. Etapas do procedimento: 1) consulta bibliográfica e aquisição de dados (azul); 2) organização dos dados em SIG (cinza); 3) geração de produtos e análises auxiliares (amarelo); 4) definição dos compartimentos da geodiversidade marinha (verde); e 5) valoração da geodiversidade e seleção das áreas-chaves (sépia).

thematic products that could be used to define geodiversity compartments such as those shown in Figure 2d):

Numerical Terrain Model (NTM): Obtained from the continuous surfaces of interpolated depth data from the GEBCO_08 Atlas. This model made it possible to obtain observations of seabed topography and other relief features associated with it.

The composition and distribution pattern of sediments and outcropping seabed materials: Owing to the absence of a regular sampling grid covering the entire area of study, a decision was made not to use traditional statistical analysis techniques for characterizing sedimentary deposits (e.g., measures of central tendency, measures of dispersion). However, analyses of the relationships between the characteristics of the elements on the seabed (composition and granulometry) and the sampling depths allowed us to establish meaningful information regarding the distribution pattern of surface sedimentary deposits.

Identification of marine landforms and marine geological structures: These landforms and structures were identified through bibliographic consultation and interpretative analyses of NTM products and available seismic profiles.

3.4. Definition of marine geodiversity compartments

Geodiversity compartments were used in this study to identify the geological environments and landscapes that constitute marine surfaces resulting from geological and geomorphological processes.

The compartments of marine geodiversity were defined according to geomorphological aspects (positioning in relation to marine physiographic region), geological (geologic age, geological environment and type of substrate) and marine landforms (underwater relief and oceanic geological structures). Criteria and parameters are shown in Table 1.

The physiographic regions were defined based on the physiographic provinces proposed by França (1979) and Palma *et al.* (2008) for the Brazilian Atlantic margin. The regions were delimited through geomorphological interpretation techniques based on the analysis of visual morphology (shape, texture, and roughness) and morphometric (depth, slope, and amplitude) aspects through NTM data. Note that such limits reflect exclusively the geomorphological features of the terrain and may not match the legal limits established by the United Nations Convention on the Law of the Sea – UNCLOS.

3.5. Valuation of geodiversity and selection of key areas

According to Brilha (2005), geoheritage is related to geodiversity elements (minerals, rocks, soils, fossils, and geoforms) and outcropping resulting from either natural geodiversity processes or human intervention.

Table 1 - Features and parameters used to define marine geodiversity compartments in the study area.

Tabela 1 - Características e parâmetros utilizados na definição dos compartimentos da geodiversidade marinha da área de estudo.

GEOMORPHOLOGICAL ASPECTS	**GEOLOGICAL ASPECTS**			**MARINE LANDFORMS**
Marine Physiographic Region	**Geologic Age**	**Geological Environment**	**Types of Substrate**	**Underwater relief and Oceanic Geological Structures**
Continental Shelf of Espírito Santo • Depth between 60 and 80 m • Flat surface with mild slopes (<0.3°) **Continental Slope of Espírito Santo** • Depth between 60–80 and 3,200 m • Uneven surface with mild to moderate slopes (3° to 25°) **Continental Rise of Espírito Santo** • Depth: 3,200 to 4,800 m • Uneven surface with smooth to steep slopes (2° to 14º). Locally upgraded forms of steep slopes. **Brazilian Abyssal Plain** • Depth: 4,800 to 5,300 m • Flat surfaces with mild slopes (0.2° to 5°). Locally upgraded forms of moderate to steep slopes. **South Atlantic Mid-oceanic Ridge (West Flank)** • Depth: >5,300 m • Uneven surfaces with moderate to steep slopes (7° to 25°). Locally upgraded forms of steep slopes.	**Mesozoic** (252 to 66 million years ago) **Cenozoic** (66 million years ago to present)	**Shallow water marine** (up to 400 m deep) **Deepwater marine** (between 401 and 1,500 m deep) **Ultra-deep waters marine** (more than 1,500 m deep) **Volcanic/Magmatic** • Eruptions and strokes associated with submarine volcanoes • Volcanic strokes associated with the magma ascent zone of the mid-oceanic ridge	**Biochemical Organic** • Organic carbonate sediments (algae and corals) • Pelagic deposits (carbonate vases) • Bioclastic deposits **Detritus** • Gravitational flow deposits and mass movement • Turbidity deposits and other bottom currents **Authigenic** • Evaporats deposits • Polymetalic nodules **Volcanic** • Alkaline • Tholeiitic	**Biogenic** • Complexes reefs **Erosive/Depositional** • Buried channel (paleochannel) • Submarine bank • Canyons and incision • Fans and turbidite channel • Plateau • Abyssal plains **Volcanic** • Volcanic buildings **Structural** • Fracture zones • Valleys and fault scarps • Salt deformation (domes and basins structural style)

The geoheritage is assigned as an individual criterion that is distinctly different from scientific, pedagogical, cultural, touristic, and other points of view. In this work, a descriptive approach was adopted to study the values and uses of marine geodiversity because of the need to raise intensive queries regarding the inventory and quantification of geoheritage mainly in the oceanic region.

The geoheritage of key areas representing the relevant aspects of the geodiversity in the Vitória - Trindade Ridge and adjacent areas was nominated based on the concept of geodiversity values established in studies conducted in continental environments, and these were adapted in the present study for application in the marine domain as the following categories: intrinsic, aesthetic, cultural, economic, functional (potential use), educational, and scientific (Gray, 2004; Brilha, 2005). The adjustment was made based on the geological context and the potential and restrictive aspects of use. The geological context was obtained through bibliographic analysis and data reinterpretation collected during the data acquisition phase.

The categories of values adopted in this study cover aspects related to the following themes:

(1) Scientific and educational interest in the geological history of the opening of the South Atlantic and formation of the brazilian continental margin - Examples Cenozoic geological history associated with variation in sea level during the Quaternary Period; Examples of mesozoic-cenozoic geological history associated with the Brazilian marginal sedimentary basins; Examples cof enozoic geological history associated with tectonomagmatic events on the Atlantic ocean; Examples of mesozoic-cenozoic geological history associated with the opening of the South Atlantic Ocean

(2) Geotouristic potential - Geological heritage registered by Brazilian body (SIGEP)

(3) Mineral potential - Deposits and mineral occurrences

(4) Functional aspects and support of biodiversity - Peculiar ecosystems

(5) Use-restrictive – geological (Hazard), anthropic (environmental degradation from infrastructure installation and predatory extraction), legal (protected areas and other areas subject to specific legislation), and technological and financial.

4. Results

The geodiversity of the Vitória - Trindade Ridge and marine adjacent areas is a result of the interaction of tectonic, volcanogenic, and sedimentary Mesozoic and Cenozoic events and reworkings by marine geomorphological processes conditioned mainly by eustatic sea level variations during the Quaternary period. Such events and processes are responsible for the great diversity of marine landscapes that depict the geological history of the planet related to seafloor spreading, the opening of the Atlantic Ocean, and formation of the BCM since the separation of the South American and African plates, which has been occurring from the Cretaceous period up to the present day.

The topography of the seabed in the study area is irregular, with depths ranging between 0 and 6,272 m below sea level, and several elevations can be observed at the seabed. Depths between 4,100 and 5,800 m are predominant; in the depth range of 3,500 and 4,800 m, a set of isobaths projected towards the African continent occurs for about 980 km, which corresponds to the Vitória - Trindade Ridge base and other underwater elevations.

From the physiographic point of view, the following marine regions can be identified from the coastline towards the offshore region (see Supporting Information):

Continental shelf of Espírito Santo (CSES)

The shelf extends for 30 to 210 km from the current coastline towards the open sea to the shelf break, and this region ranges in depth from 60 to 80 m. It features a flat surface with soft slopes that are marked by topographic gaps between 10 and 20 m. The main feature of this compartment is the significant enlargement of the shelf to the north, which corresponds to the southern portion of the Abrolhos Bank. According to Almeida (2000), this enlargement was caused by intense Cenozoic volcanic manifestations associated with the contributions of river deposits in the north–central portion of the area. From the 30 m isobaths, in the NTM products, linear subvertical structures with varied widths are observed, which are interpreted as paleochannels. Such structures extend across the entire CSES towards the CSLES (see below).

Continental slope of Espírito Santo (CSLES)

The slope comprises a narrow area less than 30 km wide and delimited at the 3,200 m isobath. It comprises wavy to heavily wavy surfaces with mild to moderate slopes. The slope is interrupted by submarine ravines and canyons associated with the effects of bottom currents.

Continental rise of Espírito Santo (CRES)

The rise represents the most extensive physiographic domain of the study area, and it extends for about 1,000 km to the 4,800 m isobath. The rise presents a great diversity of forms from extensive flat surfaces to deformed areas in the shape of domes and basins formed by the movement of evaporite deposits (São Paulo Plateau) and by volcanic mounts (Vitória - Trindade Ridge submerged portion) and other isolated seamounts.

Brazilian abyssal plain (BAP)

The plain extends for 200 and 400 km to the 5,300 m isobath. It features a plane surface controlled by sea-floor topography and structures occur in uplifted areas constituting abyssal hills. The Vitória - Trindade Ridge land portion is also present here.

South Atlantic mid-oceanic ridge (SAMOR)

The ridge occurs in the study area for about 200 km from the 5,300 m isobath, which corresponds to the western flank of the ridge. The landforms present solid structural control and form valleys and ridge crests associated with fracture zones, with average amplitude of 250 m.

The surface of the seabed is composed of shallow water marine sedimentary deposits of ultra-deep deposits formed during Cenozoic events and rocks from Cenozoic volcanomagmatic events. Cenozoic deposits cover the oldest sedimentary rocks and Mesozoic–Cenozoic volcanic rocks in the Espírito Santo and Campos Basins and the oceanic crust, whose age varies from 65 to 134 million years (Maia, 2013). The total thickness of this sedimentary sequence ranges from 500 to 5,500 m, with the thinnest rocks located south of the Vitória - Trindade Ridge in the BAP region and along the western flank of the SAMOR, while the thickest occur in the region corresponding to the Espírito Santo Basin.

4.1. Marine geodiversity compartments of the Vitória – Trindade Volcanic Seamount Ridge and marine adjacent areas: key areas and potential use

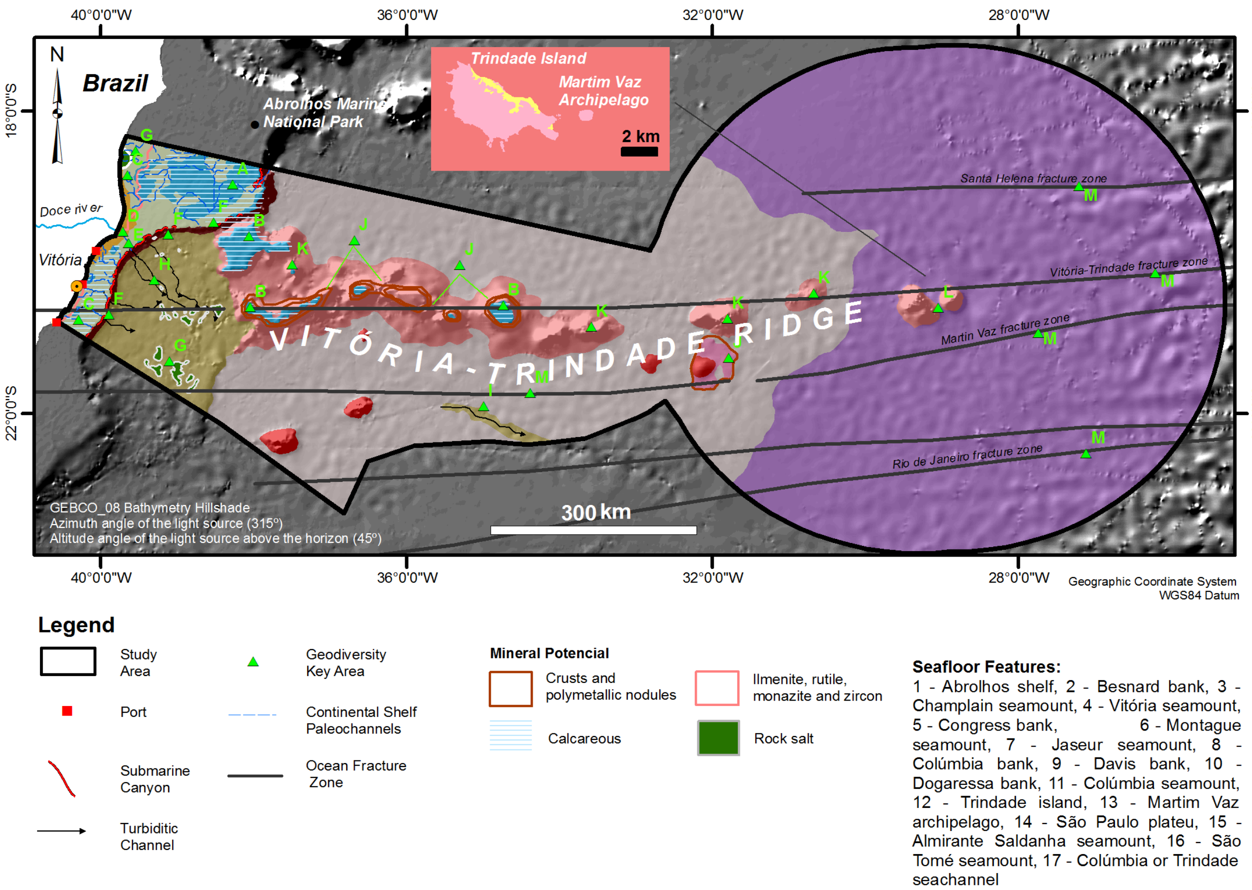
Based on the adopted methodological procedures, were identified 5 compartments of geodiversity and its subdivisions (Table 2), described according to the geological characteristics of outcropping materials at the ocean floor, submerged landforms and oceanic geological structures in the area.

Relevant aspects were selected through key areas, as described below, in terms of geoheritage and potential uses (Figure 3).

Table 2 - Corresponding to the area of marine geodiversity compartments mapped in the study area (Total Area: 739,226.977 km²).

Tabela 2 - Área correspondente aos compartimentos da geodiversidade marinha mapeados na área de estudo (Área Total: 739,226.977 km²).

Geodiversity Compartments		Area (km²)
1. Cenozoic marine deposits from shallow waters in the continental shelf of the Espírito Santo and oceanic submarine banks	1.1. Modern bioconstruction	14,849.882 - 2.008% (continental shelf: 9,295.458 - 1.257%; oceanic submarine banks: 5,554.424-0.751)
	1.3. Terrigenous deposits	1,976.483 - 0.267%
	1.4. Bioclastic deposits	16,667.956 - 2.254%
2. Cenozoic marine deposits from shallow to deep water in the continental slope of the Espírito Santo	2.1. Deposits from debris flow and submarine mass movements	4,222.437 - 0.571 %
3. Mesozoic-Cenozoic marine deposits from deep to ultra-deep water in the Continental rise of Espírito Santo	3.1. Pelagic and fine terrigenous deposits	219,905.883 - 29.748%
	3.2. Tubiditic channel and submarine fans deposits	34,912.258 - 4.722%
	3.3. Authigenic deposits (evaporite)	1,550.516 - 0.209%
	3.4. Authigenic deposits (polymetallic nodules and crusts)	2,227.010 - 0.301%
4. Cenozoic volcanism in the continental rise of the Espírito Santo and Brazil abyssal plain	4.1. Lavas and sodium-alkaline intrusions, and sedimentary deposits of the emerged portion of the Vitória - Trindade Ridge (Trindade Island and Martim Vaz Archipelag)	13.005 - < 0.0001%
	4.2. Ultrabasic-alkaline volcanic intrusions in the submerged portion of Vitória - Trindade Ridge	5,9247.306 - 8.014%
	4.3. Volcanic intrusions of unknown genesis	3,846.283 - 0.520%
5. Mesozoic-Cenozoic marine deposits from ultra-deep waters and volcanism in the Brazil abyssal plain and South atlantic mid-oceanic ridge	5.1. Pelagic deposits associated with basaltic rocks	379,807.958 - 51.378



MARINE GEODIVERSITY COMPARTMENTS OF VITÓRIA–TRINDADE RIDGE AND ADJACENT AREAS

1. Cenozoic marine deposits from shallow waters in the continental shelf of the Espírito Santo and oceanic submarine banks

1.1 - Modern bioconstructions: coral and briozoans reefs complexes

1.2 - Terrigenous deposits: mud and sandy fluviomarine

1.3 - Bioclastic deposits: sands and gravels formed from fragments of algae and skeleton

2. Cenozoic marine deposits from shallow to deep water in the continental slope of the Espírito Santo

2.1 - Deposits from debris flow and submarine mass movements: gravel and sandy-muddy sediments associated with rocks fragments and biodebris

3. 3 Mesozoic-Cenozoic marine deposits from deep to ultra-deep water in the Continental rise of Espírito Santo

3.1 - Pelagic and fine terrigenous deposits:sandy-muddy and biogenic sediments

3.4 - Authigenic deposits: polymetallic nodules and crusts

3.2- Tubiditic channel and submarine fans deposits: sandy-muddy deposits associated with detrital materials (bioclasts and lithoclasts)

3.3 - Authigenic deposits: evaporite

4. Cenozoic volcanism in the continental rise of the Espírito Santo and Brazil abyssal plain

a b 4.1 - Lavas and sodium-alkaline intrusions, and sedimentary deposits of the emerged portion of the VTR: (a) phonolite, nephelinite, and grazinites, pyroclastic deposits, volcanic conduit spills; (b) Dune fields, beaches, landslides, algal reefs, and slope deposits

4.3 - Volcanic intrusions of unknown genesis

4.2 - Ultrabasic-alkaline volcanic intrusions in the submerged portion of VTR: picrite and ancaramite

5. Mesozoic-Cenozoic marine deposits from ultra-deep waters and volcanism in the Brazil abyssal plain and South atlantic mid-oceanic ridge

5.1 - Pelagic deposits associated with basaltic rocks: pelagic clay, volcanic ash and tholeiitic basalts

MARINE GEODIVERSITY: KEY AREAS OF VITÓRIA–TRINDADE RIDGE AND ADJACENT AREAS

A - Reefs in the southern portion of Abrolhos Bank
B - Reefs above oceanic submarine banks
C - Marine granular deposits
D - Submerged portion of Doce River Delta
E - Continental shelf paleochannels
F - Systems of canyons and submarine incisions in the slope edge
G - Evaporite Deposits
H - Systems of turbidites and submarine fans in the São Paulo Plateau
I - Columbia seachannel
J - Polymetallic deposits
K - Seamounts and submarine volcanic banks of the Vitória-Trindade Ridge
L - Trindade Island and the Martim Vaz Archipelago
M - Fracture zones of the western flank of the mid-ocean ridge in the South Atlantic

Figure 3 - Marine geodiversity compartments of the Vitória–Trindade Ridge and adjacent areas.

Figura 3 - Compartimentos da geodiversidade marinha da Cadeia Vitória–Trindade e áreas

4.1.1. *Cenozoic marine deposits from shallow waters in the continental shelf of the Espírito Santo and oceanic submarine banks*

This compartment corresponds to Cenozoic *shallow waters* deposits and marine landscapes formed in the CSES region and adjacent submarine Vitória - Trindade Ridge banks. The deposits were formed by bioconstructions e and fluvial discharge action, then reworked by wave action and tides along the Quaternary:

(1.1) Modern bioconstruction: corresponds to complexes of coral reefs and bryozoans consisting of a series of marine organisms with calcareous skeletons or algae that generally develop on the volcanic substratum. Calcareous algae, rodolites, and bryozoans occur, and these are associated with bioclastic sedimentation comprising sludge, sand, and biodetritic gravel, which contains fragments of corals, gastropods, and calcareous shells of bivalves;

(1.2) Terrigenous deposits: consist of continental sediments that have been deposited and reworked in the shallow marine environment. Mud associated with the outfall of the Doce River Delta and sandy fluviomarine sediments are present; and

(1.3) Bioclastic deposits: mostly composed of bioclastic sediments, with calcium carbonate levels greater than 70%, and they are represented by sands and gravels formed from fragments of coralline algae, bryozoans, mollusks, and benthic foraminifera.

Geodiversity relevant aspects:

Key area A - Reefs in the southern portion of the Abrolhos Bank

These reefs correspond to the southern portion of the most extensive reef complex in the South Atlantic Ocean (Leão, 2002); it is similar in area to the Great Barrier Reef in Australia. The Abrolhos Marine National Park is located about 200 km north of the study area; this park was classified by SIGEP as a geobiological site. It is comprised of sources of calcium carbonate and magnesium that are used as biofertilizers and are employed worldwide in agriculture and civil construction. Economic exploitation in this region is currently barred by Brazilian governmental bodies as a measure to protect the local ecosystem. These environments are sensitive to sea-level oscillations and thus constitute an important marker of the changes along the Brazilian coast, especially at the end of the Holocene during the last regressive phase (Leão, 2002). They are unique ecosystems from geomorphological and biological points of view and are important for maintaining marine biodiversity that can absorb carbonic gas diluted in the sea and turn it into limestone. They are directly influenced by the composition of bedrock and terrestrial sediment supply, and importantly, they represent one example of the functional relation between geodiversity and biodiversity.

Key area B - Reefs above oceanic submarine banks

Almeida (2002) describes the presence of coral reefs on the submerged tops of the Vitória - Trindade Ridge (Besnard Bank, Vitória Seamount, Montague Seamount, and Davis Bank), that were made plane by marine erosion during the phase where the exposure of the tops occurred when the sea level reached about 120 meters below current sea level at the last glacial period during the Quaternary. Between 2008 and 2011, calcareous algae in the region (Davis Bank) were exploited for use as agricultural inputs. An authorization for mine exploration estimated to have covered a region of around 150 thousand hectares was overturned by the Brazilian Government under the claim that the reservation was beyond the Brazilian EEZ and reached into international legal waters (Cavancanti, 2011).

Key area C - Marine granular deposits

According to Cavalcanti (2011), the Brazilian continental shelf represents the most extensive carbonate deposition environment in the world. In the study area, it is comprised of bioclastic deposits arising from the breakdown of shells of organisms and coral reefs spread all over the CSES. In terrain deposits, sands and quartzo-feldspathic gravels are predominant, which are commonly associated with heavy minerals (ilmenite, rutile, monazite, and zircon); these deposits occur mainly near the mouth of the Doce River and near the southern coast of this region (Palma, 1979). They are used in civil construction and beach widening projects. The exploitation of such deposits depends on grants provided by environmental and regulatory agencies, which aim to protect the surrounding coral reefs among other important elements.

Key area D - Submerged portion of the Doce River Delta

There are several marine deltaic systems on the Brazilian coast; one of them is the Doce River Delta, the main delta in southeastern Brazil. Its submerged portion extends over an area of 200,000 km^2. The Doce River Delta stands out as an unique coastal landscape, with a progradation zone associated with the outfall of the Doce River, whose evolution is related to variations in the sea level through the Quaternary (Sunguio *et al.*, 1982). The delta is composed of landscapes peculiar to the transition region between the continental and marine geodiversity. Deltas influence the composition and distribution of sedimentary deposits, which work as barriers to the development of bioconstructions in the CSES.

Key area E - Continental shelf paleochannels

Quaternary changes in sea level resulted in the formation of channels (paleochannels) in the Brazilian shelf that were excavated during episodes of low sea level (Pleistocene) and buried by the Holocene sediments during episodes of sea level rise (França, 1979). The path of these channels suggests connectivity with the continental drainage system, with topographical expression up to the CSES edge, where they interconnect with the canyon systems of the continental slope (Maia, 2013). One of the most prominent channels, which stretches out to the continental slope, is located off the city of Vitória; it is named the Vitória Channel. Resources such as heavy minerals, diamonds, and gold associated with paleochannels are exploited economically in various parts of the world such as New Zealand, South Africa, and Japan (Cavalcanti, 2011). Palmas (1979) describes the occurrence of heavy minerals associated with paleochannels in the CSES, especially in the area of the Doce River Delta and in the southern portion of the study area. The exploitation of potential deposits in the area is subject to legal and environmental issues and factors such as financial and technological resources.

4.1.2. *Cenozoic marine deposits from shallow to deep water in the continental slope of the Espírito Santo*

This compartment corresponds to Cenozoic shallow, deep and ultra-deep waters deposits and marine landscapes located in CSLES. The deposits comprise sediments from the continental shelf transported by turbidity currents, chaotic deposits from gravitational flows (debris flows and turbidity currents), and depositional events of short duration (drops of rock, crawl, marine landslides, and collapses) from the slope itself: (2.1) Deposits from debris flow and submarine mass movements: The upper portion of these deposits is composed of sandy-muddy sediments containing gravel and biodebris associated with materials from the flow of mud and debris transported offshore. In the lower portion of the deposits, sandy-muddy sediments are predominant, with gravel and detrital material comprising bioclastic and coral fragments and material from the superficial portion of the sedimentary package.

Geodiversity relevant aspects:

Key area F - Systems of canyons and submarine incisions in the slope edge

In general, the continental slope is disrupted by canyons and incision marine landforms, by which the sediments reach the deepest regions of the ocean. It constitutes regions of high susceptibility to the development of geological processes associated with submarine mass movement and flow of debris. Such processes take place, mainly, from a high gradient of chaotic sediment accumulation and the action of geotrophic currents along the submarine slope. Accordingly, care should be taken in this region while implementing infrastructure and developing exploitation activities connected to the oil industry. Some of these geomorphic features were described by Schreiner *et al.* (2009) and identified by Maia (2013) in the south–central portion of the study area through an analysis of bathymetric data; among these features, the Regência, Vitória, Rio Doce, and Watu Norte e Watu Sul canyons and Regência ravine system stand out.

4.1.3. *Mesozoic-Cenozoic marine deposits from deep to ultra-deep water in the Continental rise of Espírito Santo*

This compartment corresponds to deep and ultra-deep waters deposits and marine landscapes located in CRES. These deposits are resulted from several geological processes that occurred through the Mesozoic–Cenozoic periods:

(3.1) Pelagic and fine terrigenous deposits: Pelagic deposition (carbonate vases) was predominant and it associated with deposits from continental sediment discharges by turbidite currents and authigenic processes. Represented by sandy-muddy and biogenic sediments that have been reworked by the bottom flow. Ash, volcanic fragments, palagonite (altered volcanic ash), manganese micronodes, magnetite, and mica are present. The coarse fractions contribute up to 10% of the total volume and comprise a wide variety of planktonic and benthic foraminifera. The bioelements include ooze, marl, foraminiferal sand, sponge spicules, echinoid shells, and fish teeth, which are associated with terrigenous sediments with predominant mica and fine quartz sand;

(3.2) Tubiditic channel and submarine fans deposits: deposits formed by turbidite flows through a system of channels and submarine fans. They occur in various regions of the continental rise, and particularly in the southwestern and southern regions of the Vitória - Trindade Ridge. In general, they are characterized by sandy and sandy-muddy deposits associated with detrital materials (bioclasts and lithoclasts). The coarse fraction is composed of mainly planktonic foraminifera, pteropods, and gastropods. Mineral elements consist essentially of grains of quartz, mica, and heavy minerals. Hydrogen sulfide was detected in these sediments;

(3.3) Authigenic deposits (evaporite): occur in the form of small diapiric outcropping near the shoreline and form conspicuous salt domes (more than 5,000 m thick) at depths greater than 300 m (Mohriak, 2008); and

(3.4) Authigenic deposits (polymetallic nodules and crusts): polymetallic nodules and crusts (iron manganese) that are widely distributed on the seabed;

Geodiversity relevant aspects:

Key area G - Evaporite deposits

The formation of Aptian evaporite deposits represents one of the major geological events that occurred during the Cenozoic in the sedimentary coastal basins of Brazil; these saline deposit movements have been reported to extend up to the recent period (Mohriak, 2008). In the Campos Basin, these deposits are associated with the discovery of oil fields known as pre-salt oil and gas fields. The displacement of evaporites led to intense structural deformation of the ocean floor and gave rise to geological domes and basins (synclines and anticlines) characteristic of the São Paulo Plateau area. They consist of rock salt associated with potassium, sulfur, sulfide, and vanadium, which is commonly used as an agricultural input. The deposits located in CSES, near the mouth of the Doce River, have been the subject of research and mining prospects. The exploitation of these rock salt deposits may decrease the dependence of Brazil on fertilizer imports.

Key area H - Systems of turbidites and submarine fans in the São Paulo Plateau

This represents one of the largest turbidite systems from the Brazilian shelf, and it is formed of extensive networks of meandering channels and turbidite fans on the irregular seabed in the northern segment of the São Paulo Plateau. The turbidite systems of the Doce River and Watu are examples of the central region in the study area (Schreiner *et al.*, 2009). They constitute areas subject to intense sedimentary transport, where the main oil and gas exploration wells are located in the Espírito Santo and Campos Basins.

Key area I - Columbia sea channel

According to Faugères *et al.* (2000) and Motoki *et al.* (2012), the Columbia Channel may be the largest and main distal turbidite system that developed in the Paleocene along basement structural grabens; its formation was the result of actions by contour currents influenced by the Vitória - Trindade Ridge. In the study area, the portion of this channel that can be mapped is located south of the ridge, extending to the southeast; this region is approximately 150 km long, 20 km wide, and its thickness, though not determined yet, is speculated by authors to be about 1 km.

Key area J—Polymetallic deposits

According to Palmas & Pessanha (2000), climatic oscillations and the participation of benthic organisms in sediment changes leading to the formation of microenvironments represent important conditioning factors in the formation of these deposits. They occur in the form of polymetallic nodules of various compositions (manganese, copper, nickel, and cobalt) that cover the CRES seabed and form a polymetallic crust on top of the Vitória - Trindade Ridge seamounts (Palma, 1979). Cobalt-rich crustal materials and polymetallic nodules have been identified in the Vitória, Montague, Jaseur, and Davis Banks in the Vitória - Trindade Ridge (CPRM, 2008); however, the technical and financial feasibility for extraction of these deposits needs to be verified through further study. In particular, thorough studies are necessary to detail economically viable deposits belonging to the Brazilian EEZ. Countries such as Japan, the United States, Russia, Germany, France, Korea, the United Kingdom, and China have shown interest in these deposits (Calvalcanti, 2011). Recently, Brazil received authorization from the International Seabed Authority (ISA), a United Nation's agency, to evaluate the economic potential of mafic cobalt-rich deposits in the Rio Grande Elevation, which is located about 1,000 km south of the study area.

4.1.4. *Cenozoic volcanism in the continental rise of the Espírito Santo and Brazil abyssal plain*

This compartment is composed of rocks and landscapes generated by tectonomagmatic activity giving rise to the Vitória - Trindade Ridge, during the Cenozoic along the CRES and BAP:

(4.1) Lavas and sodium-alkaline intrusions, and sedimentary deposits of the emerged portion of the Vitória - Trindade Ridge (Trindade Island and Martim Vaz Archipelag): The Trindade Island consists of sodium-alkaline volcanic rocks (phonolite, nephelinite, and grazinites), pyroclastic deposits, and volcanic conduit spills (Almeida, 2002). The Holocene stratigraphic units occupy a small area on the Trinidade Island (dune fields, beaches, landslides, algal reefs, and slope deposits) (Castro, 2010); geochemistry indicated bimodal magmatism with a strong Pb anomaly similar to that observed on the submerged portion of the Vitória - Trindade Ridge (Hansen *et al.*, 1998, cited in Almeida, 2002); dating carried out by Cordani (1970) revealed ages between 3.7 and 1.1 + 0.5 Ma (K/Ar). The Martim Vaz Archipelago consists of undersaturated alkaline volcanic rocks (ankaratrite, tambuschite, phonolite, and perquinite) (Castro & Antonello, 2006);

(4.2) Ultrabasic-alkaline volcanic intrusions in the submerged portion of Vitória - Trindade Ridge: studies in the submerged portion of the ridge are scarce; samples dredged in the central portion of the Vitória–Trindade Ridge (Colúmbia Seamount, Jaseur Seamount, Dogaressa Bank, and Davis Bank) reveal rocks of ultrabasic-alkaline composition (picrite and ancaramite). Dating of the rocks in the upper portion of the volcanic sequence suggests a U–Pb age of 29.8 ± 6.6 Ma (Fodor & Hanan, 2000; Skolotnev *et al.*, 2011). In bottom dredging in Davis and Dogaressa banks revealed the presence of carbonate formations that have been dated Miocene (19-24 Ma) (Skolotnev *et al.,* 2011); and

(4.3) Volcanic intrusions of unknown genesis: corresponds to intrusions into the seabed, the composition and age are indeterminate due to the absence studies.

Geodiversity relevant aspects:

Key area K—Seamounts and submarine volcanic banks of the Vitória-Trindade Ridge

This region plays an important role in providing environmental services and support to the biodiversity of the South Atlantic. It constitutes a physiographic barrier that diverts Brazil's maritime flow and favors the emergence of important resurgence areas in coastal southeastern Brazil (Silveira *et al.*, 2000). According to Gasparini & Floeter (2001), the proximity between the top of the elevations (about 25 km distance between them) and the shallow deposits (less than 150 m) makes Vitória - Trindade Ridge a "springboard" for coastal species to reach oceanic areas far from the coast, thus leading to economically exploited fishing. The use of volcanic rocks rich in potassium silicate as fertilizers through a powdered rock technique is an active area of research in Brazil. Thus, resources from volcanic seamounts may have potential for application in agriculture in the future. However, owing to mining in the oceanic areas, the legal, environmental, technological, and economic aspects of these deposits have to be further evaluated. Motoky *et al.* (2012) describe the occurrence of landslides along the slopes of these volcanic seamounts.

Key area L—Trindade Island and the Martim Vaz Archipelago

Trindade Island was discovered in 1501 by Portuguese navigators and was recognized by the Brazilian Commission of Geological and Paleontological Sites as a marine geoheritage site. It is considered the most recent volcanic manifestation above the sea in the South Atlantic. According to Almeida (2002), it represents an area of relevant interest for researches on the origin and differentiation of magmas in the oceanic crust. On Trindade Island, preserved volcanic structures that are rare in Brazilian territory (necks, radial dikes, and ash cones) can be observed along with extremely undersaturated alkaline associations representing various stages of magmatic differentiation and scenic beauties (beaches, reefs, dunes, peaks, incised valleys, plateaus, and erosive processes) (Castro, 2010; Pires *et al.*, 2013). Trindade Island and Martin Vaz Archipelago do not have touristic infrastructure, and Trindade Island is currently occupied by the Brazilian Navy, which has an observation post for national security purposes and to support scientific research. The Oceanic Islands constitute a special ecosystem of rich biodiversity resulting from the geographic isolation, and this provides suitable conditions for the existence of endemic species. As a result of the occupation by Azorean settlers on Trindade Island in the 18th century, herds of domestic animals were introduced, and these along with coastal systems processes caused erosion on the slopes and the development of gullies and landslides (Castro & Antonello, 2006).

4.1.5. *Mesozoic-Cenozoic marine deposits from ultra-deep waters and volcanism in the Brazil abyssal plain and South atlantic mid-oceanic ridge*

This compartment corresponds to Mesozoic volcanic rocks associated with Cenozoic marine deposits from ultra-deep waters and marine landscapes located in SAMOR. During ocean floor expansion through the SAMOR, extravasation of tholeiitic basalts known as mid-oceanic ridge basalts or MORB, which are responsible for the formation of the oceanic crust, occurred. The deposition of pelagic and volcanoclastic sediments was associated with basalts that formed the new oceanic crust:

(5.1) Pelagic deposits associated with basaltic rocks: consist of calcareous slate and clay turbidites reworked by an underflow on older sedimentation and even the outcropping of rocks from the oceanic crust, which are represented by tholeiitic basalts. The deposits consist of yellowish-brown pelagic clay, which is suggestive of slow deposition conditions, along with stains, manganese nodules, volcanic ash, mica, manganese lenses, and occasionally, quartzose fine sand. The carbonate content is low or absent (<2%). In the coarse fraction, manganese nodules and palagonite are common. Eventually, quartz granules, mica, and more rarely, fragments of sedimentary rocks are observed. Bioelements include fish teeth, sponge spicule fragments, echinoid spicules, planktonic foraminifera, diatoms, and radiolarians.

Geodiversity relevant aspects:

Key area M—Fracture zones of the western flank of the mid-ocean ridge in the South Atlantic

They represent features extending in an approximately W–E direction and are diagonal to the SAMOR accretion area of the oceanic crust. Such structures are associated with the rupture and separation of the South American and African lithosphere plates, which occurred in the Mesozoic (Almeida, 2002).

Fracture zones are represented on the surface as crests and structural valleys (inactive fracture zones), as seen in the continental portion in the form of the Alto do Vitória that separates the sedimentary basins of Campos and Espí-rito Santo (Alves *et al.*, 2006; Schreiner *et al.*, 2009).

This region represents one of the few areas in Brazil under the SAMOR physiographic domain, and it is classified in the literature as the Santa Helena, Martin Vaz, Rio de Janeiro, and Vitória-Trindade fracture zones in the Vitória - Trindade Ridge (CPRM, 2008). The geological environment is favorable to the formation of polymetallic sulfide deposits related to hydrothermal vents. It is located in ultra-deep waters, and mineral exploitation would depend on financial and technological resources.

Table 3 summarizes the geoheritage and aspects of use of the key areas that represent relevant Vitória - Trindade Ridge geodiversity compartments and marine adjacent areas.

5. Discussion and final considerations

This study proposes a regional-scale model to characterize marine geodiversity on the seabed. The model was based on information available in literature and on the reinterpretation of bathymetric, geological, and geophysical data. Such an approach was adopted mainly because of the lack of systematized information on this type of physical medium, and it was adapted directly to geodiversity characterization procedures. The application of this model to the Vitória - Trindade Ridge and adjacent areas has proved satisfactory for the macroscale characterization of the diversity of the geological features and marine landforms.

The Vitória - Trindade Ridge and adjacent areas display unique aspects of marine geodiversity that are of national and international importance. These features are related to the evolutionary processes of the South

Table 3 - Geoheritage and aspects of use of the key areas representing the geodiversity of the Vitória–Trindade Ridge and adjacent areas.

Tabela 3 - Patrimônio geológico e aspectos de uso das áreas-chaves representativas da geodiversidade da Cadeia Vitória–Trindade e áreas adjacentes.

Thematic Category of Geodiversity Values	Geoheritage and Potential Use	Marine Geodiversity: Key Areas
I – Scientific and educational interest in the geological history of the opening of the South Atlantic and formation of the brazilian continental margin	• Examples cenozoic geological history associated with variation in sea level during the Quaternary Period	A, B, D, E, F, H,
	• Examples of mesozoic-cenozoic geological history associated with the Brazilian marginal sedimentary basins	A, B, D, E, F, G, H,
	• Examples cof enozoic geological history associated with tectonomagmatic events on the Atlantic ocean	*K, L*
	• Examples of mesozoic-cenozoic geological history associated with the opening of the South Atlantic Ocean	G, *M*
II – Geotouristic potential	• Geological heritage registered by Brazilian body (SIGEP)	A, *L*
	• Special marine landform	A, B, D, E, F, G, H, I, *K, L*
III – Mineral potential	• Deposits and mineral occurrences	A, B, C, E, F, G, J, *K*
IV – Functional aspects and support of biodiversity	• Peculiar ecosystems	A, B, D, *K, L*
V – Use-restrictive aspects	• Geological: Hazard	F, G, H, *K, L*
	• Anthropic: environmental degradation from infrastructure installation and predatory extraction	A,
	• Legal: protected areas and other areas subject to specific legislation	A, B, C, D, E, G, J, *K*
	• Technological and financial	B, C, D, E, G, J, *K*

Note: A - Reefs in the southern portion of Abrolhos Bank, B - Reefs above oceanic submarine banks, C - Marine granular deposits, D - Submerged portion of Doce River Delta, E - Continental shelf paleochannels, F - Systems of canyons and submarine incisions in the slope edge, G - Evaporite Deposits, H - Systems of turbidites and submarine fans in the São Paulo Plateau, I - Columbia seachannel, J - Polymetallic deposits, K - Seamounts and submarine volcanic banks of the Vitória-Trindade Ridge, L - Trindade Island and the Martim Vaz Archipelago, and M - Fracture zones of the western flank of the mid-ocean ridge in the South Atlantic

Atlantic Ocean surge, BCM implementation, and sea level fluctuations throughout the Quaternary. Notable examples of Brazilian geodiversity of scientific, geotouristic, economic, and educational interest were identified. These included submarine volcanic mounts, fracture zones associated with the mid-oceanic ridge, evaporite movement through the sedimentary package, paleochannels, deltas, canyons, turbidite systems, mineral deposits (biogenic limestone, marine granulated, and polymetallic rock salt), and areas susceptible to mass movements along submarine slopes as a result of geological processes (i.e., hazards).

Some supporting relationships between geodiversity and local biodiversity were identified. For example, the most important reef formation in the South Atlantic developed on a platform that was extended by volcanic effusions in the northern portion of the study area (Abrolhos Bank). Additionally, the development of bioconstructions on elevated areas of the Vitória - Trindade Ridge favor the appearance of corridors for coastal species that can use them, because of their shallow depth and proximity to ridge banks and seamounts, to travel long distances from the coast.

Overall, this manuscript is intended to aid in the generation and dissemination of knowledge about Brazilian marine geodiversity and to provide support for additional studies aimed at the evaluation, conservation, utilization, and management of abiotic marine resources. Furthermore, the proposed characterization model can be applied to other regions of the Brazilian continental shelf and adjacent areas.

The information obtained through geodiversity surveys, when paired with biotic, social, and legal information, can play an important role in seabed planning activities, thus facilitating geoconservation and the management of conflicts of interest. It also constitutes the first step for selecting representative areas to study Earth's geological history. Examination of resource management measures in geologically diverse areas and protection of such areas for present and future generations is necessary since the use of the continental shelf and adjacent areas for various purposes is increasing. Moreover, information obtained through geodiversity surveys can foster the creation of specific legislation for preserving geodiversity and biodiversity, as in Europe.

Issues such as the inventory, assessment, and conservation of geoheritage sites need to be further researched. There are several methods for the quantification and selection of geoheritage sites (geosites) in continental areas, which depend on the degree of scientific knowledge, representation (diversity and rarity), accessibility, educational value, extent of preservation, and interest level (local, regional, national, and global). However, there is a lack of such studies that consider these aspects in marine environments. Hence, more such studies in marine environments would be valuable.

Appendix

Supporting Information associated with this article is available online at http://www.aprh.pt/rgci/pdf/rgci-565_Ranieri_Supporting-Information.pdf

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Integrated coastal management in Brazil: analysis of the National Coastal Management Plan and selected tools based on international standards*

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ABSTRACT

The Integrated Coastal Zone Management (ICZM) in Brazil is a political-institutional process, manifested in the establishment of the National Coastal Management Plan (NCMP) and in the formulation and implementation of specific tools for territorial planning in the coastal zone, as well as other activities related to ICZM in Brazil. This work analyses some official documents related to the Brazilian NCMP and to the frequently used tools for performing ICZM in Brazil: Macrodiagnostic of Coastal Zone, Orla Project and Coastal Ecological and Economic Zoning. The analysis is based on legislative, ecological and socio-economic indicators, found in the Handbook for Measuring the Progress and Outcomes of Integrated Coastal and Ocean Management, published in 2006 by the Intergovernmental Oceanographic Commission. The results indicate adequacy of NCMP and tools on the definition and delimitation of the coastal zone, as the institutional processes of coordination and cooperation within the ICZM and about the diagnostics and the territorial planning of the coastal zone. However, the Brazilian NCMP as the cited tools still need to fully meet the major global goal of the ICZM, as internationally defined by the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP), with respect to the improvement of the life quality of coastal populations who depends on the sea resources and with respect to the environmental conservation of the Brazilian coastal zone. With the wide dissemination of results, is expected to contribute to the improvement of NCMPs and ICZM tools maintained worldwide, since we emphasize the importance of including the international general objectives of the ICZM, as well as inclusion the dimensions of sustainability in the ICZM processes, so try to ensure economic growth, coupled with respect to coastal populations and environmental conservation in coastal areas.

Keywords: Integrated coastal zone management, tools for coastal diagnostic and zoning, coastal indicators, sustainable development.

RESUMO

Gerenciamento costeiro integrado no Brasil: análise do Plano Nacional de Gerenciamento Costeiro e de instrumentos selecionados com base em parâmetros internacionais

O gerenciamento costeiro integrado no Brasil é um processo político-institucional, que se manifesta na instituição do Plano Nacional de Gerenciamento Costeiro (PNGC) e na formulação de ferramentas específicas ao planejamento territorial da zona costeira, além de outras atividades relacionadas ao gerenciamento. O presente trabalho apresenta a análise de documentos oficiais relacionados ao PNGC e a algumas das ferramentas frequentemente utilizadas na execução do GCI no Brasil: o Macrodiagnóstico da Zona Costeira, o Projeto Orla e o Zoneamento Ecológico e Econômico Costeiro. A análise tem por base os indicadores ecológicos, socioeconômicos e de legislação, encontrados no manual para medição do progresso e dos

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resultados do gerenciamento integrado costeiro e oceânico (Handbook for Measuring the Progress and Outcomes of Integrated Coastal and Ocean Management), publicado em 2006 pela Comissão Oceanográfica Intergovernamental. Os resultados indicam adequação do PNGC e das ferramentas selecionadas quanto à definição e delimitação da zona costeira, quanto aos processos institucionais de coordenação e cooperação no âmbito do GCI e quanto ao diagnóstico e ao planejamento territorial da zona costeira. No entanto, tanto o PNGC quanto as ferramentas analisadas ainda precisam melhor atender à meta global do GCI, como definido internacionalmente pelo Grupo Integrado de Especialistas sobre os Aspectos Científicos da Proteção Ambiental Marinha (acrônimo inglês: GESAMP), no que concerne à melhoria da qualidade de vida das populações costeiras que dependem dos recursos do mar e quanto à conservação ambiental da zona costeira brasileira. Com a ampla divulgação dos resultados, espera-se contribuir para a melhoria dos PNGCs e de ferramentas de gestão costeira mantidos em todo o mundo, uma vez que ressalta-se a importância da inclusão dos objetivos gerais do GCI a nível internacional, além da inclusão das dimensões da sustentabilidade nos processos de GCI, de modo a tentar garantir o crescimento econômico, aliado ao respeito às populações costeiras e à conservação ambiental nas zonas costeiras.

Palavras-chave: *Gerenciamento integrado da zona costeira, ferramentas para diagnóstico e zoneamento costeiros, indicadores costeiros, desenvolvimento sustentável.*

1. Introduction

The coastal zone gives the perception of a vast and seemingly endless ocean which changes as its waters collide with the continental edges, giving rise to a geographic area that represents the transition from a wet to a dry environment. The coastal zone, as initially defined by the Brazilian Federal Law Nº. 7661, dated 16th May 1988, is defined as “the geographic space of interaction of air, sea and land, including its resources, renewable or not, covering maritime and terrestrial zones, which will be defined by the Plan” (*authors translation*).

Komar (1988) highlights the diversity and temporality of the uses of the coastal zone, in addition to its sensitivity to climatic, hydrodynamic and social events, weakens the environment and emphasizes the need for implementing planning and management policies that aim to regulate land uses and mitigate the residual effects of the conflicts. Port activity with its collective logistics, tourism, fisheries, industrial development and real estate growth, exemplify the activities of more than 50% of the world's coastal population (Bird, 1996), and are some of the variables of the equation of the region. In a suitable illustration, the same author points out that if all the inhabitants of the world’s Coastal Zones decided to go to the coast at the same time, there would be less than 13 cm^2 of space for each one of them.

The spatial localization and conformation of coastal municipalities in Brazil actually are reflections of a historical pattern of coastal occupation: “the first Lusitanian settlements in Brazilian lands were located, with very few exceptions, in the coastal zone” (Moraes, 2007: 33). Considering that Brazil is a territory whose colonization manifested itself through the exploitation of resources to be exported to European markets, it is natural that urban occupation was originated in the coastal zone, since export activity logistics is favored by the proximity to the ocean. This pattern is critical, given that coastal areas are among the most dynamic areas of the world, in relation to both their physical and socioeconomic aspects.

Since that environmental concerns extend from air and water pollution to plans of land use and occupation (Ferreira, 1998), greater emphasis is being given to the integrated management that guides and constrains the use of natural resources, aiming to preserve for future generations. Following this view, diagnostic activities, zoning and planning are essential to the success of the integrated coastal zone management (ICZM) process in countries bordering the sea.

The ICZM is a dynamic process which aims, through a set of actions and inter-sectoral participation, to improve the quality of life of people living in the coastal zone and promote sustainable development by protecting ecosystems and coastal resources. According to Gesamp (1996), the approach used in the ICZM comprises four components: geographic, temporal, sectoral and political-institutional. Its development process involves generation of five consecutive stages:

i) identification and preliminary evaluation of relevant aspects;
ii) preparation of the program;
iii) formal adoption and funding;
iv) implementation; and
v) evaluation.

The process is continuous and restarts at the end of the fifth stage, until the program is perfected (GESAMP, 1996). Since it is an ongoing process, the perfection is a goal that will never be achieved.

The ICZM is consistent with the sustainable development objectives, since it seeks to integrate the economic, social, ecological, and political-institutional dimensions of the coastal zone, as seen in the overall goal of the ICZM: *Integrated Coastal Management (ICM) is a process that unites government and the community, science and management, sectoral and public interests in preparing and implementing an integrated plan for the protection and development of coastal ecosystems and resources. The overall goal of ICZM is to improve the quality of life of human communities who depend on* *coastal resources while maintaining the biological diversity and productivity of coastal ecosystems. (GESAMP, 1996: 2)*

Pickaver *et al.* (2004) point out that the ICZM is an important tool to incorporate the conservation and sustainable use of marine and coastal biodiversity. Given the plurality of contrasting niches in the coastal zone, the need arose for a specific policy for the coast, which would promote the development of economic and tourism activities, while protecting environmental, cultural, heritage and historical values (Freitas, 2007).

The National Coastal Management Plan (NCMP) was instituted in Brazil by Federal Law Nº 7661, dated 16th May 1998, which, according to Diegues (2001), aims to promote rational use of the coastal zone resources, in order to raise the population quality of life, and to protect its natural, historic, ethnic and cultural heritage. This Law established only the main guidelines of coastal management and the actions of states and municipalities, standardizing the methodology to be applied (Freitas, 2007). Later, the NCMP was approved by the Resolution Nº 001, dated 3rd December 1990, of the Brazilian Interministerial Commission of the Resources of the Sea (ICRS) (Portuguese acronym: CIRM), which provides objectives, guidelines and programmed actions, tools, rules for the macro diagnostic and the monitoring of the Brazilian coastal zone. This Resolution establishes the competencies and the source of resources to make operational the Brazilian NCMP.

Posteriorly, the Resolution Nº. 005, dated 27rd November 1997, revised the Brazilian NCMP, establishing general standards for environmental management of the Brazilian coastal zone, determining that the boundaries in which the guidelines of coastal management are to be followed, delineating two bands covered by the plan - the maritime band, which corresponds to the Brazilian territorial sea; and terrestrial band, which corresponds to the group of coastal municipalities under direct or indirect influence of the sea, even if not situated right on the waterfront.

Federal Decree Nº. 5300, dated 7th December 2004, which regulated the Federal Law Nº 7661/88, provides more specific rules for use and occupation of the coastal zone, establishing criteria for the management of the waterfront. This Decree adopts two bands and creates another one, both of them used as guidance on the application of *Orla Project*: the coastline, delimited on the sea side by the 10 m isobath and on land by the linear distance of 50 m in urbanized and of 200m in non-urbanized areas, from the high tide line (or the end limit of adjacent terrestrial ecosystem).

The Brazilian NCMP is based on the decentralization of strategy implementation and decision-making, which specifically places the municipalities in the sphere of

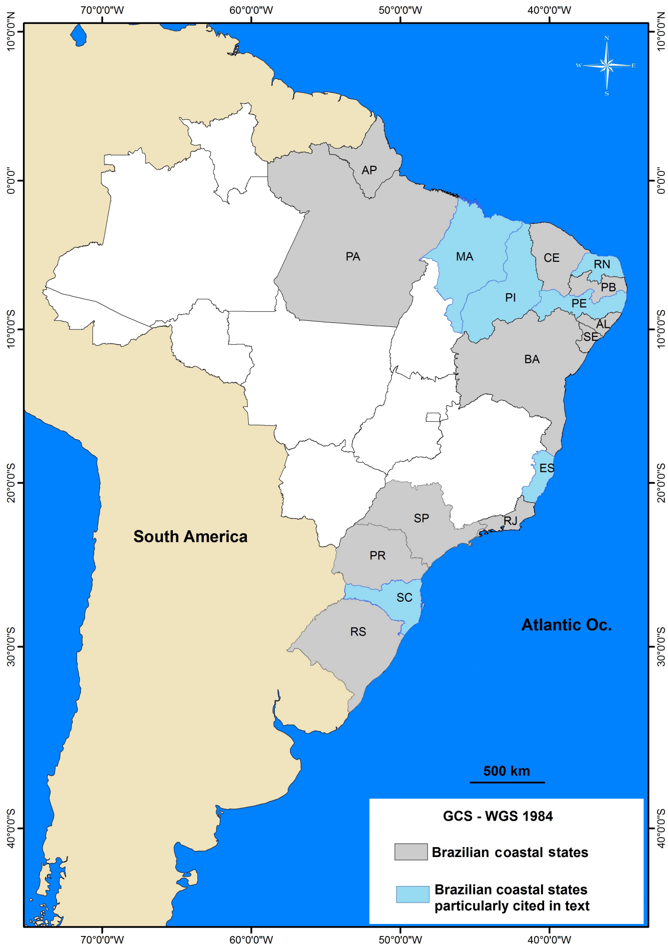

Figure 1 - Brazilian coastal states, highlighting the states particularly mentioned in the text.

Figura 1 - Estados costeiros do Brasil, com destaque para os estados particularmente mencionados no texto.

local implementation. This fact is very important, since municipalities acquire the knowledge of the coastal aspects and its environmental problems in more detail than the National Level.

The NCMP also expect that coastal municipalities implement their Municipal Coastal Plans (MCP), in accordance with the NCMP and State Coastal Plan (SCP) guidelines.

This Brazilian coastal management strategy, which includes the three levels of government action, favors the application of the principles of sustainable development. But, the sustainable development in the coastal zone also requires the adoption of holistic and systemic approaches. The holistic approach requires an interdisciplinary overview that integrates different processes due to the wide diversity of the coastal zone components.

The systemic approach evaluates the overall system and its component systems, keeping in mind the principle that the whole is not merely the sum of its parts, as described by Bossel (1999: 10): *In complex real systems,* *this is a recursive relationship: systems depend on other systems that depend on yet another set of systems, and so on. (...) The human societal system, its component systems, and the resource and environmental system on which they depend, are complex dynamic systems.*

The complexity involved in real dynamic systems requires extensive use of information derived from the formulation and application of indicators, to track the progress or the state of its aspects. Such indicators are essential to support management in any geographical scale. However, to be really useful, these indicators must be chosen carefully to provide information on the most relevant aspects of the problem. Another warning relates to the care needed in formulating the associated indices, so that the obtained information is more accurate and meaningful as possible. An excellent list of desirable characteristics for indicators in general can be obtained from Meadows (1998).

According to the planning for the ICZM, some tools that promote diagnosis and management of the coastal zone in Brazil are highlighted: Coastal Ecological Economic Zoning (CEEZ), Coastal Zone Macrodiagnostic (hereafter referred to as *Macrodiagnostic*) and Waterfront Integrated Management Project (hereafter, *Orla Project*).

In Brazil, Ecological Economic Zoning (EEZ) is an instrument for planning and managing the territory according to Federal Law Nº. 6938, dated 31th August 1981 (that provides the national environmental policy in Brazil). The EEZ was posteriorly regulated by the Federal Decree Nº. 4297, dated 10th July 2002, that regulates the article 9, section II, of the Federal Law Nº 6938/81: *Art. 9th - are instruments of national environmental policy:* (...) II – *the environmental zoning;* (...)" (*authors translation*).

The competences for the execution of the EEZ in Brazil are established by the Presidential Decree, dated 28th December 2001: *Provides for the Coordinator Commission for the Ecological and Economical Zoning of the National Territory and the Permanent Working Group for the implementation of ecological-economic zoning, institutes a permanent Working Group for the Implementation of ecological-economic zoning, called Consortium ZEE-Brasil, and gives other measures.*

Brazil does not has a federal legislation dedicated to regulate the CEEZ in the country. This subject is treated as one of the instruments provided by the ICRS Resolution Nº 005/97, which establishes the observance of the zoning criteria for the national territory: *The coastal ecological-economic zoning is the guiding instrument for the regional planning process, required to obtain the environmental sustainability conditions to the development of the coastal zone, in accordance with the guidelines of the ecological-economic zoning of the national territory. (authors translation)*

According to Federal Decree Nº. 4297/02 (Chapter 2), Brazilian States can develop its EEZ in conjunction and cooperation with the Federal Government: *Art.6th - Incumbent upon the Federal Government develop and implement national or regional EEZ, especially when you have as object biome considered national patrimony or that should not be treated a piecemeal manner. (...)* §1st *The Federal Government may, by entering appropriate document, develop and implement the EEZ in conjunction and cooperation with the States, the conditions required this Decree. (...)Among the technical assumptions, the enforcers of EEZ must submit: I – comprehensive reference term; II - coordination team composed of technical staff enabled; III - methodological compatibility with the principles and criteria approved by the Coordinating Committee of the Zoning Ecological-Economic National Territory, established by Decree of December 28th, 2001 (...). (authors translation)*

According to the 3rd article of the Presidential Decree dated 28th December 2001, the works of zoning will be conducted using an interdisciplinary approach and systemic view, enabling the analysis of cause and effect, allowing the establishment of relationships of interdependence between physical and biotic subsystems and socio-economic.

In some initiatives developed in Brazilian States, like the CEEZ of Espírito Santo (ES), the diagnosis of nature sensitivity and social potential allows to define areas relatively vulnerable to use and takes into consideration physical and social variables at local and regional levels, in order to suggest a use for each area after assessing its resilience. Thus CEEZ emerges as an important planning tool, by using indicators of socio-environmental variables, which, when combined, can generate social vulnerability indexes. These indexes should be taken into account during decision making for installing enterprises, identifying priority conservation areas, localizing urban settlements, together with the aspects of valuation and valorization of the waterfront (Moraes, 2007).

The *Orla Project* confers a local character to the implementation of coastal territorial planning, since 2004. It is based on the premise of joint management of the waterfront's land-use and occupation by the federal, state, and municipal governments, and society.

The proposal of the *Orla Project* was included as priority in the Brazilian Federal Action Plan for the Coastal Zone (FAPCZ), from 1998, under the Ministry of Environment, Water Resources and Legal Amazonia (Portuguese acronym: MMA) (GI-Gerco, 1998: 19): *It is observed, so that both the seafront, as the track Navy Coastal Zone, are under federal domain, and its man-*

agement, largely defined in the structure which deals with all the features and all dimensions, with such national wealth in the custody of the Union. This fact justifies that the programming of a series of activities, consolidated a specific line of work of the Federal Action Plan, is dedicated to coordination process led by Union Heritage Secretariat in implementation of the "Maritime Orla Project", dedicated to review the federal performance in matter, updating the concepts and measurements used and reviewing the emphyteusis and grants use of these spaces, taking into account, including, the guidelines included in the environmental legislation of the country. Emerge here, clearly, a priority of the Federal Action Plan. (authors translation)

Since 2001, some Brazilian states were instituted as pilots of the *Orla Project*: Rio Grande do Norte (RN), Piauí (PI), Santa Catarina (SC) and Espírito Santo (ES) (Oliveira & Nicolodi, 2012). In 2003, the Secretary of the Heritage of the Union (Portuguese acronym: SPU), an agency under the Ministry of Planning, Budget and Management (Portuguese acronym: MP), in partnership with the Ministry of Environment, was incorporated into the management of the *Orla Project*.

The objective of the *Orla Project* is to "implement an Integrated Management Plan to direct the use and occupation of land in bands along the rivers and seas" (MMA, 2005). The main assumptions of the *Orla Project* are the following:

i) the coastal zone is seen as a national asset, with its use subject to environmental protection (according to § 4 of Article 225 of the Brazilian Federal Constitution, dated on 1988);
ii) public lands would be seen through their socio-environmental function; and
iii) civil society transcends from the position of the beneficiary to that of co-manager in the development and monitoring of policies, together with other federal entities.

Hence, the *Orla Project* is a joint initiative between the policies of land and socio-environmental heritage, and its guidelines value the actions that promote sustainable use of coastal resources and the strengthening of links between the different stakeholders (MMA, 2005). Thus, the *Orla Project* aims to regulate the use of coastal space, combining physical environment support variables with current socioeconomic and urbanization scenarios, as well as to try to preserve the parts not yet urbanized or in the process of urbanization.

Macrodiagnostic is an instrument of the Federal Decree Nº 5300/04, and aims to gather information, on a national scale, on biophysical and socioeconomic characteristics of the coastal zone, in order to dictate actions of preservation, conservation, regulation and supervision of natural and cultural heritage. The initiative originated in the ICZM assessment process conducted in Brazil in the early 1990s, which culminated in its first national coastal Macrodiagnostic (MMA, 1996).

The *Macrodiagnostic* published in 2008 uses environmental risk analysis as a methodological basis and considers three dimensions: natural risk, technological risk and social risk; in addition to three basic criteria: sensitivity of natural systems, density and potential expansion of the productive structure, and degree of criticality of the habitability conditions (MMA, 2008). Taussik (2007) quotes a useful example of managing coastal risk in United Kingdom and alleges that the legislation for the regulation of the development and for the protection of coastal populations against coastal flooding, erosion and instability share the objective of the minimizing the risk.

This work aims to contribute with the ICZM process in Brazil, presenting the key strengths and weakness of the Brazilian NCMP and of some tools used to execute the coastal management in Brazil: Macrodiagnostic of Coastal Zone, Orla Project and Coastal Ecological and Economic Zoning. More widely, this work aims to expose some aspects of the legal documents related to the ICZM in Brazil, in comparison with international standards, and propose the analysis of Brazilian official documents related to the ICZM in the country (which regulates the NCMP and the selected tools) with some recognized international concerns standards, from the IOC and from the GESAMP. Thus, this work aims to collaborate with others ICZM processes, developed worldwide.

The results indicate that the official documents related to Brazilian NCMP and the cited tools provide detailed definition and delimitation of the coastal zone of Brazil; of the same mode, these analyzed official documents provide the rules for the institutional processes of coordination and cooperation within the ICZM and for the diagnostic and the territorial planning of the coastal zone. However, the NCMP as the cited tools still need to fully meet the major global goal of the ICZM, as internationally defined by Gesamp (1996), with respect to the improvement of the life quality of the coastal populations who depends on the sea resources and with respect to the environmental conservation.

2. Material and methods

To achieve the goals, this work presents the analysis of the Brazilian NCMP and of the cited coastal management tools, based on legislative, ecological and socioeconomic indicators, found in the *Handbook for Measuring the Progress and Outcomes of Integrated Coastal and Ocean Management*, published in 2006 by the Intergovernmental Oceanographic Commission (IOC, 2006) and based on the overall goal of the ICZM, hereafter referred to only as *Handbook,* according to the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP, 1996). In order to perform the analysis of the Brazilian NCMP and selected tools, we proceeded in two steps. Both are based in the *Handbook*, and in the overall goal of the ICZM, according to Gesamp (1996).

The first step consisted of an analysis of the legislation that detailed the Brazilian NCMP (ICRS Resolution Nº 001/90 and ICRS Resolution Nº 005/97), according to criteria referred to the indicator "G2- Existence and adequacy of legislation enabling ICOM", from the *Handbook*. This indicator aims to support "integrated management through adequate legislation and regulations" (IOC, 2006: 24). In this way, the indicator adopt the parameters:

i) existence of legislation on coastal and marine resources and

ii) adequacy of the ICZM legislation.

Generic and more detailed provisions are presented too (IOC, 2006: 117). The adopted criteria for the analysis of the Brazilian NCMP were:

i) incorporating the sustainable development principles, specifically for oceans and coasts;

ii) supporting ICZM goals and objectives;

iii) establishing procedures for institutional coordination and cooperation and

iv) defining interventions and management activities under the ICZM scope.

This analysis was realized comparing some of the legal documents related to the Brazilian NCMP (ICRS Resolution Nº 001/90 and ICRS Resolution Nº 005/97) with the adopted criteria. These Resolutions were selected because they detail the operationalization rules for the implementation of the ICZM in Brazil, presented in the NCMP dated on 1990 and its revision, on 1997.

The second step consisted of the analysis of the CEEZ (and some EEZ´s initiatives referred to the coastal Brazilian States), the *Orla Project* and the *Macrodiagnostic*. The analysis adopts as reference the parameters of the socioeconomic indicators, SE1 to SE13 (IOC, 2006: 50) and to the ecological indicators, E1 to E9 (see supporting information) (IOC, 2006: 38), presented in the *Handbook*. The analysis focus on the:

i) coverage of cited socioeconomic and ecological parameters (supporting information) and

ii) ability to provide ecological and socioeconomic information pertinent for the Brazilian coastal management, having as reference the ICZM objectives as defined by GESAMP (1996).

In the same way, official documents referred to these three tools were discussed, according to the adopted criteria.

3. Results and discussion

3.1. Analysis of Brazilian NCMP

3.1.1. Analysis of the Brazilian NCMP regarding the sustainable development principles and the international goals and objectives of the ICZM

ICRS Resolution Nº 001, dated 3rd December 1990, which approves the Brazilian National Coastal Management Plan (NCMP), adopts the systemic and holistic view, but addresses six principles, closely limited to environment (a little bit ecological) and political dimension of the sustainability:

1 - The National Coastal Management Plan will be developed and implemented based on the National Policy for Marine Resources.

2 - Protection of coastal ecosystems, which will be used in compliance with the criteria laid down by law, under conditions ensuring environmental preservation.

3 - Maintenance and expansion of the fishing capacity of the waters of the territorial sea, through the conservation of mangroves, estuaries and other coastal formations.

4 - Protection and rehabilitation of the remaining areas that are representative of natural ecosystems of the coastal zone.

5 - Control and rehabilitation of degraded and disfigured areas in the coastal zone.

6 - Rational use of resources of the coastal zone, through the knowledge of environmental dynamics, under a systemic / holistic approach.

The ICRS Resolution Nº 005, dated 27th November 1997, which approves the National Coastal Management Plan II (NCMP II), establishes general standards for environmental management of the coastal zone and creates the Integration Group of Coastal Management (Portuguese acronym: GI-Gerco). This resolution emphasizes, in the introductory section, the close relationship between the sustainability of human activities and environmental conservation, and expresses the commitment of the Brazilian government to the sustainable development of its coastal zone: *The National Coastal Management Plan (NCMP) expresses the commitment of the Brazilian government to the sustainable development of its Coastal Zone, considered as a national heritage (...)*

This commitment in ICRS Resolution Nº 005/97 is represented by twelve principles, which includes the socioeconomic and cultural dimensions, beyond the environmental and political dimensions of the sustainability, presented in the ICRS Resolution Nº 001/90: *The integrated management of Coastal Zone terrestrial and marine environment(...) The sustainable use of coastal* *resources (...) The consideration, on the terrestrial part, of the areas marked by socio-economic and cultural activity (...) and its area of immediate impact, from the effects of these activities, on shaping the coastal territory.*

The sustainable development goals are markedly expanded in the ICRS Resolution Nº 005/97, but the effects of socioeconomic activities are considered only on shaping the terrestrial and not the marine domain. This is a serious shortcoming, since offshore oil exploration is becoming increasingly important in Brazil. Another shortcoming of the approach adopted in the ICRS Resolution Nº 001/90 and in the ICRS Resolution Nº 005/97 is that it does not define clearly the preservation of biological diversity and ecosystem productivity of the coastal zone, because it focuses on the sustainable use of natural resources (in the ICRS Resolution Nº 001/90), or physical changes in the coastal territory (in the ICRS Resolution Nº 005/97). The sustainable use of natural resources is strictly related to not extrapolate the load capacity of the ecosystems.

Both two ICRS Resolutions, do not provide tools or actions to improve the quality life of the coastal populations who depends on coastal resources, which is one of the global goals of the ICZM, according to Gesamp (1996).

On the other hand, both the ICRS Resolutions adopt components of the ICZM approach: geographic, temporal, sectoral and political-institutional, according to Gesamp (1996).

3.1.2. Analysis of the Brazilian NCMP regarding institutional coordination and cooperation

The ICRS Resolution Nº 001/90 and the ICRS Resolution Nº 005/97 establish the competencies for coastal management in Brazil for government sectors at the federal, state and municipal levels. The ICRS Resolution Nº 005/97 is more specific and provides mechanisms for cooperation, whether in the form of boards; or in the form of inter-sectoral and inter-agency coordination activities with relevant agencies and boards implemented by Ministry of Environment; or in joint activities with states and municipalities for the implementation of conservation units, promoted by the Brazilian Institute of Environment and Renewable Natural Resources (Portuguese acronym: IBAMA). The ICRS Resolution Nº 005/97 retains the authority of the Ministry of Environment as the main coordinator of the ICZM in Brazil, expands its powers and defines two groups to support its activities (GI-Gerco and a subgroup of Integration of States, linked to GI-Gerco).

GI-Gerco is a group of coastal management integration, formed under the ICRS, whose mission is to promote the coordination of FAPCZs. The Subgroup of Integration of States, has the mission of to promote the coordination of states among themselves and with the federal government on general coastal management issues in Brazil (Resolution Nº 001, 1997).

The duties of IBAMA, state and local governments remain the same under the ICRS Resolution Nº 005/97, with municipalities having the additional duty to uphold the compatibility of their tools of spatial planning with CEEZ (Resolution Nº 001, 1997).

The boards, provided by the ICRS Resolution Nº 005/97 are groups suitable for coastal management, composed of representatives from public and private sectors and society organizations, allowing discussions and forwarding policies, plans, programs and actions involving the main actors of the coastal zone, being consistent with the participation principles explained in ICZM.

Thus, it is observed that the ICRS Resolution Nº 005/97 is clear regarding the powers and duties of the main public actors in coastal management in Brazil and the definition of joint mechanisms between the three levels of government.

A noteworthy detail is that the sources of public funding for the implementation of NCMP in Brazil are defined in the ICRS Resolution Nº 001/90 and in the ICRS Resolution Nº 005/97. Both the Resolutions do not clearly regulates the mandatory character of including the coastal management plans execution in the budgets of the three government levels, even if it has been established by the mentioned Resolutions.

3.1.3. Analysis of the Brazilian NCMP regarding intervention activities

ICRS Resolution Nº 001/90 provides the execution of the CEEZ in Brazil and provides the use of the results like criteria for zoning, which will guide the intervention activities in the coastal zone.

In ICRS Resolution Nº 005/97, intervention activities are implied in the statement of one of the planned actions for coastal management, which requires compatibility of NCMP actions with public policies that focus on the coastal zone.

The government plays a lesser role on intervention activities in both Resolutions, since only interventions at the local level are clearly defined. Thus, the Brazilian government is limited to providing information or planning. More than that, the Brazilian government should act as a regulator of coastal areas, so as not to allow the prevalence of speculative and vested interests in coastal management related decision-making. The Brazilian NCMP could have a key role within the ICZM process in Brazil, providing the main guides for intervention actions. Hence, the main characteristic of the plans should be, precisely, the prediction of intervention actions in coastal areas.

But specific rules for the intervention actions in the Brazilian coastal zone are provided by the Federal Decree Nº 5300, dated 7th December 2004, which regulates the Federal Law Nº 7661/88. This providence was useful to establish some degree of governmental intervention for the coastal zone occupation and for the uses of its space and resources.

3.1.4. Analysis of the Brazilian NCMP regarding definition of management activities

The ICRS Resolution Nº 001/90 and the ICRS Resolution Nº 005/97 predict numerous tools (management, diagnosis, or information), but differ as to the delimitation of coastal areas and the actions to be implemented for their management.

Regarding implementation of coastal management activities, ICRS Resolution Nº 001/90 provides some tools for Brazilian ICZM: the EEZ, the coastal monitoring (with different levels of action), the information system for the ICZM in Brazil (Portuguese acronym: SIGERCO) and management plans (or programs), according to specific issues:

i) Implantation of Conservation Units Plan;

ii) Environmental Education Plan;

iii) Scientific Development and Diffusion of Adequate Technologies Plan;

iv) Programs to Support Emergences and Accidents;

v) Programs for the Ecotourism;

vi) Recovery of Degraded Areas Plans;

vii) Plan of Investments on collect, treatment and disposal of solid and liquid effluents and

viii) Plans for the management of watersheds.

Regarding implementation of coastal management activities, ICRS Resolution Nº 005/97 presents a set of actions whose objective is to systematically regulate ICZM in all levels of government in Brazil. These actions address coordination, implementation, integration and planning, aiming at producing plans and instruments designed to support coastal management. Furthermore, provides seven tools for the ICZM in Brazil:

i) the State Coastal Plan (SCP);

ii) the Municipal Coastal Plan (MCP);

iii) the SIGERCO;

iv) the System for the Environmental Monitoring of the coastal zone (Portuguese acronym: SMA-ZC);

v) the Report of the Environmental Quality of the coastal zone (Portuguese acronym: RQA-ZC);

vi) the ZEEC and

vii) the Plan for Management of the coastal zone (Portuguese acronym: PGZC), which differs from the NCMP, because establishes more participation of society in its formulation and implementation .

It is observed that, although the actions are more or less specified, whether under a specific (Resolution Nº 005, 1990) or a general (Resolution Nº 005, 1997) viewpoint, neither mentioned Resolutions defines a timeline for implementation, thus, making this process extremely slow. The presence of an implementation schedule, even with only some of the planned actions (given that there is still much to be done), would clearly place coastal management as a priority within the Brazilian government commitments.

3.2. Analysis of some tools frequently used in Brazilian ICZM

The three analyzed tools in this work utilizes the spatial planning as the main guideline. Taussik (2007: 612) analyzes the spatial planning tools and legislation in England and its intersection points with the ICZM goals: *Spatial planning has a wider interpretation [than town and country planning]. It can be used to apply to any activity with a spatial, or geographical, dimension, be it on land or in marine environment, and concerns where a particular activity or development can be undertaken. Its tools including zoning, which can be combined with temporal controls. Coastal/marine activities demonstrating spatial dimensions include: new development, nature conservation, coastal defence and shoreline management; the regulation of minerals on and off-shore; and fisheries.*

An analysis based on the guidelines of Federal Decree Nº 4297, dated 10th July 2002, which establishes criteria for the implementation of the EEZ, shows, from the natural environmental perspective, some consistency with the *Handbook*, especially for the parameters of biodiversity assessment and conservation, protection of ecologically important areas (such as breeding sites of species), primary productivity, recovery and preservation of areas for use and management of water resources. Also, the EEZ Decree comprises the premises of sustainable development, which is also concerned in Handbook: *The process of elaboration and implementation of the EEZ: I - focus the ecological, economic and social sustainability, in order to reconcile economic growth and protection of natural resources, for both present and future generations (...)*

However, except the determination of four classes of reference scale for generation of the EEZ cartographic charts, especially 1:250.000 to 1:100.000 for the coastal zone, no other specific methodological guidelines for coastal and maritime areas are cleared included. There is also no specified issues about what is considered vulnerability and potential assessment methodology, which innately leaves government agencies responsible for implementing it, although more detailed methodology is proposed in Macrodiagnostic. However, we observe methodological proposals for the establishment of EEZs from the Strategic Affairs Secretariat of the Presidency of the Republic (Portuguese acronym: SAE/PR) and Sustainable Development Secretariat of the Ministry of Environment (Portuguese acronym: SDS/MMA), although they contain only principles and general guidelines. On the other hand, it is noteworthy the organizational character of the instrument, which assumes the cooperation between the different spheres of public administration and the need to apply local criteria in evaluating the system.

Consideration of the geological/geomorphological aspects as well as description of oceanographic processes do not appear to be consistent within the guidelines of the EEZ (as defined in the Federal Decree Nº 4297/02) or within the ecological indicators of the *Handbook*. Although, some parameters presented in the Handbook appear in the CEEZ of Espírito Santo (Portuguese acronym: ZEEC-ES): wave climate, width of the continental shelf and geomorphology: *In the context of geology and physics, the criteria were selected according to the availability of data and the possibility of satisfactory interpretations to ensure the representation of interactions, as suggested by Jimenez et al. (2008) and Muehe (2001), between: topography and geology; type / morphology of the coastline; and bathymetry and wave dynamics. (IEMA, 2010: 135, authors translation).*

Also appears in the CEEZ of Pernambuco (PE), (Portuguese acronym: ZEEC-PE) for example, as quality of water on the continental shelf. In the EEZ of Maranhão (MA) (Portuguese acronym: ZEE-MA), geomorphological aspects of the coast are observed, though not directly related to the coastal hydrodynamics processes.

Regarding socioeconomic variables, in general, there is notable consistence with the parameters affecting quality of life, represented in the guidelines of EEZ by health, labor market, housing, education and sanitation. Sustainable development, defined in the *Handbook* as the preservation of resources to be passed on to future generations, is contemplated and emphasized in the EEZ guidelines by acknowledging "the intrinsic value of biodiversity and its components".

The *Orla Project*, in this context, fills a systematization and coordination gap at the local level (specifically the City) regarding the coastal zone planning and management. Thus, the spatial focus of this project is the waterfront as an integral part of the coastal zone, responsible for its natural and economic support (MMA, 2005). From this premise, the *Orla Project*, divided into four deployment guides, aims at analyzing the shoreline regarding its natural (beach geomorphology, coastal dynamics, biodiversity and natural resources) and socioeconomic (real estate, industrial activity, tourism, fishing, others) features in order to classify, plan its development and regulate its use.

Observation of the physical-environmental factors (supporting information) included in the *Orla Project* aligns with the guidelines for diagnosis and planning suggested by the *Handbook*, which values the natural factors as important for planning purposes. The O*rla Project* stands out as another approach consistent with the *Handbook*, which addresses the legal question of the property regime of the coastal areas. Given the overlap between federal government, municipalities, and private lands, the basis for planning is prioritizing the resolution of legal disputes of land ownership, as well as the legal aspects applicable to every sphere of ownership. Hence, the legal consideration of the public beach, since construction of buildings very close to it can affect public access and use. Moreover, there are many property aspects and interests involved in shoreline occupation, making real estate adequacy a priority for planning purposes.

Meanwhile, the coastal zone shared management under the *Orla Project*, shows the importance given to public participation in the implementation of this project, raising awareness of its importance, execution of activities and decision-making. This displays another adequacy aspect, as is proposed in the basic guidelines of the *Handbook* which support decentralized management and popular participation in a bottom-up approach of the ICZM. The advantages of this decentralized strategy for the ICZM is in relief in Zagonari (2008), Ernoul (2010), Ballinger *et al.* (2010) and Cooper (2011).

Regarding the coverage of socioeconomic parameters suggested in the *Handbook*, the *Macrodiagnostic* disregards a wide range of issues that are critical to support activities of conservation and monitoring of the natural and cultural patrimony of the coastal zone (supporting information). For example, the *Macrodiagnostic* does not include total fluctuating population or some specific conditions for quality of housing (such as access to clean water or the houses located in hazardous areas) in Social Risk. In Technological Risk, it only includes activities related to the extraction and production of oil and natural gas (while there are a number of other economic activities that directly impact the coastal zone). It does not account for several different loads of pollutants and the introduction of ballast water, nor does it consider the amount of economic investment by government and private sector. It is noteworthy that much of this information is regularly produced by governmental bodies of nationwide jurisdiction like the Brazilian Institute of Geography and Statistics (Portuguese acronym: IBGE) and the Institute for Applied Economic Research (Portuguese acronym: IPEA).

Regarding coverage of ecological parameters suggested in the *Handbook*, it is observed that the *Macrodiagnostic* considers certain information related to biodiversity, but disregards other, oceanographic information, which is fundamental in Natural Risk, since it is related to primary (biomass and quality of habitat) and secondary productivity/production and to the risk of species extinction. In Technology Risk, it could include information related to fishing activities (e.g. quantifying by catch, adequacy of the fishing fleet, the level of government subsidy to fisheries development and the adequacy and control of fish farming activities). Unfortunately, much of this information suggested here is not systematically produced by government agencies, but can be so by state environmental agencies, provided there is a methodological standardization and coordination effort in this direction by Ministry of Environment. More broadly, the absence of such information reflects the still little attention paid by the Brazilian government to oceanographic monitoring, essential for the activities of the ICZM in the country, given its large coastline.

3.3. Key Results

Finally, the key results are summarized in the following lists. They are useful for the remark of the highlights obtained from this work. And an additional list with the cited legislation in the paper is also presented.

3.3.1. Key results with respect to the analysis of the Brazilian NCMP

- The analysis of the selected legislation related to the Brazilian NCMP (ICRS Resolution N° 001/90 and ICRS Resolution N° 005/97) showed some general characteristics of the Brazilian NCMP:
- The Brazilian NCMP includes the three level of governmental acting and provides mechanisms to its cooperation; also establishes the decentralization of strategy of the implementation and decision-making processes related to the ICZM in Brazil;
- The Brazilian NCMP establishes detailed zoning of the Brazilian coastal zone, considering two bands (one terrestrial and other, maritime). This zoning is used as guideline to the implementation of the tools related to the ICZM in Brazil;
- The inclusion of the municipalities that are not situated right on the waterfront in the Brazilian Coastal Zone shows the importance of the watershed as a geographical unit of analysis;
- There is a expressed commitment of the Brazilian government to the sustainable development of its coastal zone (in Resolution N° 005/97), but the social and the ecological dimensions need to be better represented in the rules and tools provided to the implementation of the ICZM in Brazil; and
- The intervention level of the government in the Brazilian Coastal Zone still needs to be improved, because this is done mainly in the national level and could be extended to the others two spheres (state and municipal). The Brazilian government could act as a regulator of coastal areas in all the three governmental levels, so as not to allow the prevalence of speculative and vested interests in coastal management related decision-making;

3.3.2. Key results with respect to the analysis of the selected tools

- The EEZ is consistent with the biodiversity and conservation parameters as well as adopts an integrated view between different spheres of decision-making; However, it needs more detailed methodological guide, regarding a better adequacy between plans of different states;
- The *Orla Project* aims to understand the waterfront in a integrated view between natural and social aspects, as well as considers the property regime of the coastal areas. Still, fills a systematization and coordination gap at the local level (specifically the City) regarding the coastal zone planning and management;
- The *Macrodiagnostic* considers issues of biodiversity as well as introduces a more consistent methodology for coastal vulnerability assessment, but lacks of some oceanographic aspects; still, does not consider some social parameters as quality of housing or other important social issues, as suggested by the Handbook;

4. Conclusions

This work aimed to analysis the Brazilian NCMP and some of the most frequently used tools for performing the ICZM in Brazil. It was based on legislative, ecological and socioeconomic indicators suggested by the *Handbook for measuring the progress and outcomes of the integrated coastal and ocean management*, considered here as a valid representation of standardization and consistent coverage of indicators for sustainable coastal zone management, on international intergovernmental level, and especially because it is believed to be the only one in the world up to now in these terms. In this respect, Ye *et al.* (2014) cited the *Handbook* as a valid reference for the evaluation of the ICZM processes, based on the formulation of state and process indicators. The same authors accentuate the general absence of an integrated approach, between the socio-economical, governmental and environmental coastal dynamics.

The analysis was also based in considerations presented in Gesamp (1996), about the global goal of the ICZM.

Results showed that the Brazilian NCMP seems to be adequate in defining and delimiting the coastal zone areas, in creating processes for institutional coordination and cooperation within the ICZM, and in planning for the use of the coastal zone. However, the Brazilian NCMP still need to include important aspects to meet the overall goal of the ICZM, which is improving the quality of life of the population living in coastal areas, conserving biological diversity and productivity of coastal ecosystems (GESAMP, 1996). A list of the key strengths and weaknesses of the Brazilian NCMP is showed below.

Key strengths of the Brazilian NCMP

- Establishes the competencies and the source of resources to operationalize the ICZM in Brazil and establishes mechanisms for cooperation (Resolution Nº 005, 1997);
- Establishes general standards for environmental management of the Brazilian Coastal Zone, determines the boundaries in which the guidelines of coastal management are to be followed, and delineates two bands covered by the plan: the maritime band and the terrestrial band;
- Includes, in the terrestrial band, municipalities that are not situated right on the waterfront (Resolution Nº 005, 1997). This providence is important, because includes municipalities that belong to the same watershed of the municipalities situated right on the waterfront, reinforcing the importance of the watersheds as an geographical unit of analysis;
- Is based on the decentralization of strategy implementation and decision-making, which specifically places the municipalities in the sphere of local implementation; this is important since municipalities acquire the knowledge of the coastal aspects and its environmental problems;
- Includes the three levels of government action;
- The commitment of the Brazilian government to the sustainable development of its coastal zone is clearly expressed in twelve principles (Resolution Nº 005, 1997);
- Adopts components of the ICZM approach: geographic, temporal, sectoral and political-institutional, according to Gesamp (1996); and
- Provides some tools to operationalize the ICZM in Brazil, including plans, systems for monitoring and reports;

Key weaknesses of the Brazilian NCMP

- Even if the ICRS Resolution Nº 005/97 contains the expressed commitment of the Brazilian government to the sustainable development of its coastal zone, the effects of socioeconomic activities are considered in this Resolution only on modelling the terrestrial domain and it does not clearly includes the marine domain. This is a serious shortcoming, since offshore oil exploration is becoming increasingly important in Brazil;
- Both two ICRS Resolutions (Nº 001/90 and Nº 005/97), do not provide explicitly tools or actions to improve the quality life of the coastal populations who depends on coastal resources, which is one of the global goals of the ICZM, according to Gesamp (1996);
- Both two ICRS Resolutions (Nº 001/90 and Nº 005/97) do not define clearly the preservation of the biological diversity and of the ecosystem productivity in the coastal zone, because it focuses on the sustainable use of natural resources (in the ICRS Resolution Nº 001/90), or physical changes in the coastal territory (in the ICRS Resolution Nº 005/97);
- Both the ICRS Resolutions (Nº 001/90 and Nº 005/97) do not clearly regulates the mandatory character of including the coastal management plans execution in the budgets of the three government levels;
- The government plays a lesser role on intervention activities in both ICRS Resolutions (Nº 001/90 and Nº 005/97), since only interventions at the local level are clearly defined. Thus, the Brazilian government is limited to providing information or planning; and
- Both the ICRS Resolutions (Nº 001/90 and Nº 005/97) do not define a timeline for implementation, thus, making the ICZM process extremely slow in Brazil. The presence of an implementation schedule, even with only some of the planned actions (given that there is still much to be done), would place practically the coastal management as a priority within the Brazilian government commitments.

Both EEZ and *Orla Project* are spatial planning tools with legal and conceptual support, albeit under different legal approaches. The EEZ is established legally by Federal Decree Nº 4297/02 (although already proclaimed by Article 225 of the Brazilian Federal Constitution of 1988 and the Federal Law Nº 6938/81, the Brazilian National Environmental Policy). The *Orla Project* is based on several other existing legal aspects (Statute of Cities, NCMP, Property Regime Act, Federal Action Plan, among others), which already makes it consistent with the basis for the execution of the ICZM in Brazil, thus giving the necessary legal support.

The *Orla Project* appears to be more adequate regarding operational aspects when compared to the international references adopted in this work, despite the fact that the EEZ presents guidelines for the representation on a regional scale. However, both EEZ and *Orla Project* represent spatial planning tools applied to the ICZM in Brazil, albeit in different ways, which together strengthen the premise of planning as a biased categorization of sustainable development in the coastal zone.

A list of the key strengths and weaknesses of the Brazilian NCMP is showed below.

Key strengths of the selected tools

- Are legally established by the Government;
- Are decentralized regarding to decision-making between the govern and other stakeholders;
- Are already implemented in some states, and are being reviewed in others, which leads to an improvement of Brazilian acquired experience;
- Focus on strategic planning and improvement of land use in the coastal zone;
- Embrace sustainable development as a premise as well as other relevant environmental issues concerned to the coastal zone;
- Are able to reflect local particularities for managing the coast.

Key weaknesses of the selected tools

- Although legally established by federal government, the tools have different legal character, but not mandatory;
- Lack of priority investments in the public spheres responsible for the tools management;
- Lack of uniform or more detailed methodology as a guide for some parameters of coastal vulnerability to climate changes, in order to homogenize the results of all Brazilian coastal states, especially which refers to CEEZ;
- Poor environmental data, especially the long term monitoring procedures, which are the basis for implementation of the coastal management tools.

It is noteworthy that the NCMP and all the tools analyzed in this may also include important aspects for the ICZM in Brazil, regarding the control of commercial and industrial activities (including accounting and controlling pollutant loads and introduction of ballast water), control of recreation activities, biodiversity quantification and protection (including biomass quantification and quality assessment of habitats) and the adequacy of fisheries and aquaculture (including quantifying and controlling by catch, adequacy of the fishing fleet, assessing fish farming ventures and quantifying the government subsidy level to fisheries development).

The proposal to compare plans and coastal management tools in Brazil with the *Handbook* guidelines (IOC, 2006) does not intend to adopt or recommend a standard or completely based on international standards methodology. Evidently, the coastal zone has intrinsic local characteristics, in this sense, should the plans and management initiatives be flexible to suit local conditions. However, the purpose of this study was mainly detect the lack of parameters or management processes considered important in international level that may be useful for the development of coastal management in Brazil.

Finally, the results here obtained should be useful to contribute with the ICZM processes, in order to evaluate and detect the main strengths and weaknesses regarding the main plans and coastal planning initiatives in Brazil, and likewise, the main point congruence within the international reference management guide. Once the plans and initiatives should be reviewed periodically, this work can contribute suggestively in the adoption of detailed methodologies for local risk assessments to sea level variations and other forms of land use regulation. Additionally, this work aims to highlight the importance of the international parameters to the perfectioning the ICZM processes worldwide.

Appendix

Supporting Information associated with this article is available online at http://www.aprh.pt/rgci/pdf/rgci-531_Klumb-Oliveira_Supporting-Information.pdf

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How many pellets are too many? The pellet pollution index as a tool to assess beach pollution by plastic resin pellets in Salvador, Bahia, Brazil*

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ABSTRACT

Plastic pellets are significant components of marine litter and can be found floating in the sea or stranded on beaches. However, current assessments of this issue lack standardization to allow comparisons of pellet pollution levels between different locations. Thus, the present study proposes the Pellet Pollution Index (PPI) to classify beaches based on the amount of pellets found in a given area of superficial sand. Pellets were sampled from 24 sites (P01 – P24) along the municipality of Salvador, Brazil, within a quadrat of 1 x 1 x 0.05m on the strandline and backshore. Twenty-two sites were located along the oceanic coastline, while the remaining 2 sites were within the Todos os Santos Bay. Results showed that, considering the coastline of Salvador as a whole, the PPI indicated a very low degree of pollution. This approach should aid future attempts of locating and removing the plastic anthropogenic component of the sediment on beaches and in marine environments.

Keywords: Plastic Pellets, Sandy Beaches, Pellet Pollution Index, Beach Pollution, Coastal Management

RESUMO

Quantos pellets são pellets demais? O índice de poluição por pellets como uma ferramenta para analisar poluição de praias por pellets de resina plástica em Salvador, Bahia, Brasil

Pellets plásticos são componentes significantes do lixo marinho e podem ser encontrados flutuando no mar ou encalhados em praias. No entanto, análises atuais dessa problemática não apresentam padronização que permita comparações de níveis de poluição por pellets entre diferentes locais. Assim, o presente estudo propõe o Índice de Poluição por Pellets (PPI) para classificar praias de acordo com a quantidade de pellets encontrados em uma dada área superficial de areia. Pellets foram amostrados em 24 pontos ao longo do município de Salvador, Brasil, dentro de um quadrado de 1 x 1 x 0,05m na linha de detritos e no pós-praia. Vinte e dois pontos se localizavam na orla oceânica, enquanto os 2 pontos restantes estavam dentro

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da Baía de Todos os Santos. Os resultados demonstraram que a orla de Salvador como um todo apresentava um grau muito baixo de PPI. Essa abordagem poderá auxiliar em iniciativas para a localização e remoção do componente antropogênico plástico do sedimento de praias e do ambiente marinho.

Palavras-chave: *Pellets plásticos, praias arenosas, Índice de Poluição por Pellets, poluição de praias, gerenciamento costeiro.*

1. Introduction

Industrial plastic pellets are composed of plastic resins – usually polyethylene, polystyrene or polypropylene, that are 2 – 5 mm in diameter and are used as raw material in the production of plastic items (EPA 1993; Ogata *et al.* 2009). These spherules can reach the marine environment, and eventually become deposited on sandy beaches, during their production, transport or use. Due to their small size and resemblance to food items, plastic pellets are ingested by a wide range of marine organisms (Tourinho *et al*. 2010; Buxton *et al*. 2013; Rebolledo *et al*. 2013). In addition, chemical compounds in the sea water, such as persistent organic pollutants (POPs), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and pesticides can become absorbed onto the pellets which, when ingested, may trigger bioaccumulation (Ogata *et al*. 2009; Yamashita *et al*. 2011) and biomagnification processes (Endo *et al*. 2005; Frias *et al*. 2010; Karapanagioti *et al*. 2011), posing threats especially to apex predators, which include marine animals and humans.

Until recently, marine litter assessments in general focused on quantifying and qualifying the sampled material, but there was no index which classified sandy beaches according to their pollution degree by solid waste. Thus, Alkalay *et al*. (2007) proposed the Clean Coast Index (CCI) to classify sandy beaches according to the amount of plastic present in beaches. Furthermore, they determined that plastic debris could be used as a proxy for all types of litter, because plastic is the most abundant material comprised in marine litter. However, this classification does not encompass plastic pellets in its calculation, since only particles larger than 2 cm are considered.

Various studies have been conducted worldwide concerning the presence of plastic pellets on beaches focusing mainly on the quantification of pellets (Gregory 1977, 1978; Shiber 1979, 1982; Shiber & Barrales-Rienda 1991; Ivar do Sul *et al*. 2009; Costa *et al*. 2010; Turner & Holmes 2011; D'Antonio *et al*. 2012) and their external/physical (Corcoran *et al*. 2009; Fotopoulou & Karapanagioti 2012) or chemical characteristics (Endo *et al*. 2005; Ogata *et al*. 2009; Frias *et al*. 2010; Karapanagioti *et al*. 2011, Lithner *et al*. 2011; Rochman *et al*. 2013). However, no studies were found in the literature that classified sandy beaches according to pollution (presence) by pellets. This hinders the communication, both for the scientific community and general population, of the information provided by various studies that observed the abundance of this material in a variety of beaches worldwide. Similar to what motivated the creation of the CCI, plastic pellet evaluations still lack a tool that allows the classification of a beach according to its degree of pollution by pellets. Thus, we propose the Pellet Pollution Index PPI and apply to beaches of the municipality of Salvador, Brazil.

2. Materials and Methods

2.1. Sampling site

The municipality of Salvador has a coastline of approximately 40 km (Figure 1), which is characterized by the presence of more rectilinear sectors (i.e. the sector between P15 – P17 and P18 – P21), promontories (i.e. near P05), and sectors with pocket beaches (i.e. Paciência Beach, P08) that are intersected by rocky outcrops, both basement rock and beach sandstone.

Salvador is a metropolis with over 2.6 million inhabitants (IBGE 2010). The municipality's beaches, especially those located within the Barra district (P03 and P04 in Figure 1), are intensely used by tourists and local beachgoers, attracted by both the natural beauty and the historical and cultural relevance of the region.

The coastline is highly urbanized, with very few well established backshore areas due to the presence of anthropogenic structures to support the beachside avenue. As shown in Figure 1, there are numerous urban river and rainwater drainages that discharge straight on the municipality's beaches. According to Fernandino (2014), in addition to fulfilling their role in draining water to the ocean, these drainages represent a source of litter and potentially also pellets to the marine environment, because industries that use plastic pellets as raw-material can easily lose some of this material during handling.

2.2. Pellet sampling

Plastic pellets were sampled from the beaches of Salvador during the rainy season (winter) of 2012 (June to August) and the dry season (summer) of 2013 (February). A total of 24 sites were sampled: 22 sites every 1 km along the coastline of Salvador extending northwards from the Porto da Barra beach (P03), at the entrance of the Todos os Santos Bay (TSB), to the lighthouse in Itapuã (P24) (see Figure 1). In addition, two sites located within the TSB were sampled, Ribeira (P01) and Boa Viagem (P02), in order to compare the

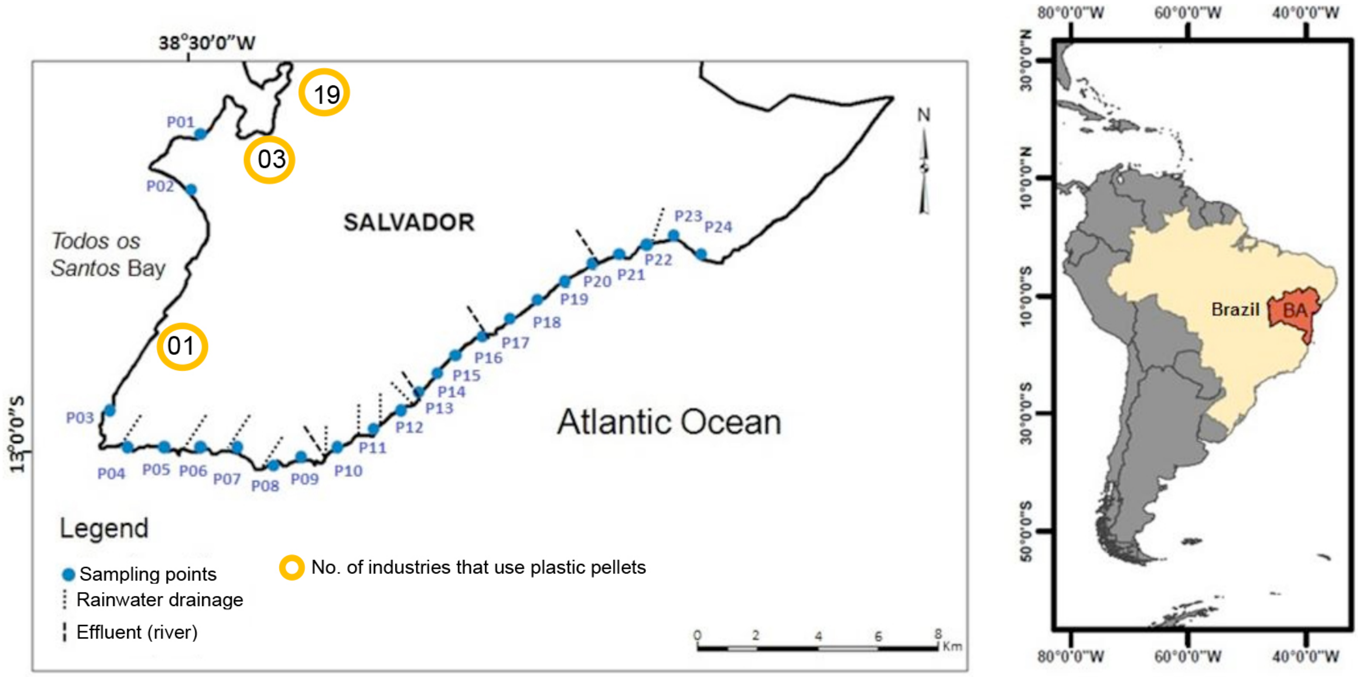

Figure 1 - The study area showing sampling sites.

Figura 1 - Localização da área de estudo e pontos de amostragem.

concentrations of plastic pellets with open coastline sites, particularly due to the presence of the port of Salvador.

At each site, a 1 x 1 x 0.05 m quadrat was placed on the strandline of the last recent high water mark and a second one was surveyed by the landwards obstacle that limited the sand strip. This obstacle could be either natural (e.g. vegetation or dunes) or anthropogenic (e.g. walls and other constructions). This landwards area was generically called "backshore" in the present study. The superficial layer of sediment within the quadrat, respecting the maximum depth of 0.05 m, was removed and immersed in a bucket with seawater to separate the plastic pellets through flotation. This superficial sampling was chosen in order to evaluate recent deposition of plastic pellets for future inference of hydrodynamic-meteorological factors and/or events which governed their deposition. As reported by Turra *et al.* (2014), the distribution of pellets throughout the sediment column is variable, and, as such, the index proposed in the present study should be applied to the uppermost strata of sediment to avoid over or underestimating the level of pollution.

2.3. Data Analysis

The data collected were digitized and primarily analyzed using a worksheet on the software Excel (Windows Office 2010). The statistical analysis of the abundance (i.e. absolute number of pellets) and concentration (i.e. number of pellets per m^2) of pellets was performed through the Kruskal-Wallis test (BioEstat. 5.3) in order to verify the existence of significant differences between the sampled seasons.

2.4. Pellet Pollution Index - PPI

The calculation of the PPI was performed as shown in Equation (1), using the ratio between the number of pellets and the volume of sediment sampled. This ratio was then multiplied by a correction coefficient p ($p = 0.02$), arbitrarily determined to conveniently classify the result within a range of 0 to 3 according to the degree of pollution as follows: very low ($0.0 < PPI \leq 0.5$); low ($0.5 < PPI \leq 1.0$); moderate ($1.0 < PPI \leq 2.0$); high ($2.0 < PPI \leq 3.0$); and very high ($PPI > 3.0$).

$$PPI = \left[{n(items)}/{a(m^2)} \right] \times p, \qquad (1)$$

where n is the amount of sampled pellets, a is the area of sampled sediment and p is the correction coefficient.

Table 1 presents the classification of the degree of pollution by pellets and the numerical abundance. The column with numerical data was included in order to provide a comparative numerical order of magnitude between raw data and the index.

In cases where the strandline and the backshore overlapped, due to the interruption of the backshore by anthropogenic obstacles, only one quadrat was sampled. Thus, for the calculation of the PPI, the area of sediment for those sites corresponded to half the area of the other sites.

3. Results and Discussion

In total, 1,967 pellets were sampled from the beaches of Salvador. Of these, 1,102 were sampled during the winter of 2012 and the remaining 865, during the summer of 2013. From the 24 sampled sites 20 presented plastic

Table 1 - Concentration of pellets and Pellet Pollution Index (PPI) classification.

Tabela 1 Concentração de pellets e classificação pelo Índice de Poluição por Pellets (PPI).

PPI	Concentration of pellets	Classification
$0.0 < PPI \leq 0.5$	0 – 25	Very Low
$0.5 < PPI \leq 1.0$	25 – 50	Low
$1.0 < PPI \leq 2.0$	50 – 100	Moderate
$2.0 < PPI \leq 3.0$	100 – 150	High
$PPI > 3.0$	> 150	Very high

pellets deposited on the superficial layer of sand (83.33%) during the winter, and 18 (75%) contained pellets during the summer.

The mean number of pellets observed at each site was 45.92 (SE = 12.89) during the winter of 2012 and 36.04 (SE = 9.66) during the summer of 2013. During the winter, the site with greatest abundance was P11 (Pituba beach; 265 pellets), followed by P16 (Boca do Rio beach; 155 pellets), and by P12 (Jardim dos Namorados beach; 129 pellets). During the summer, site P04 (Barra beach) presented the greatest abundance, with 196 pellets, followed by P16 (Boca do Rio beach; 125 pellets), and by P07 (Paciência beach; 79 pellets). During the winter, P01 (Ribeira beach), P02 (Boa Viagem beach), P23 (Itapuã beach) and P24 (Farol de Itapuã beach) did not present pellets. During the summer, sites P01 (Ribeira beach), P03 (Porto da Barra beach), P05 (Othon Hotel beach), P22 (Piatã Duna beach) and P24 (Farol de Itapuã beach) did not present pellets. The number of total pellets collected did not vary significantly ($p > 0.05$) between summer and winter.

The very low concentration of pellets on the beaches located towards the TSB during the studied seasons suggests that either the port area/activities are not a major source of pellets for those beaches or the circulation patterns of the TSB do not provide conditions which allow for their deposition at these locations. Moreover, as mentioned previously, the constant presence of urban river drainages and effluents that discharge straight onto the municipality's beaches can also represent a source of pellets, which could explain the absence of pellets in P24, for example, since there are no drainage outputs on this site.

Plastic pellets were sampled from a total of 86 m² of superficial sediment. Thus, an overall mean value of 23.26 pellets m^{-2} (SE = 4.6) was obtained for the entire coastline, which results in a PPI of 0.46, meaning a very low degree of pollution by plastic pellets. The density of pellets sampled during the winter of 2012 was higher (26.20 pellets m^{-2}, SE = 7.61, PPI = low degree) than during the summer of 2013 (20.31 pellets m^{-2}, SE = 5.27, PPI = very low degree). The PPI was determined for each site as shown in Figure 2.

During the winter, most of the sampled sites (75%) presented a very low PPI. The categories "low", "moderate" and "high" each represented 8.33% of the total of sampled sites. During the summer, 66.67% of the sites were classified as having a very low PPI, followed by the classifications "low" (20.83%) and "moderate" (12.5%). No sites presented "very high" PPI in either season.

In order to assess the applicability of the PPI as a tool for improving the comparison of results obtained from different study sites, the index was used to classify several national and international studies gathered through literature review (Table 2). The values for pellet density (No. pellets m^{-2}) were either directly provided by the authors in the consulted literature or had to be calculated using the information available in each article (sampling area in m² and number of sampled pellets).

By standardizing the measurement of the occurrence of pellets on sandy beaches it is possible to observe that this type of pollution varies immensely. The frequency of a very high degree of pellet pollution observed on several beaches is concerning. This finding should encourage studies to also identify the possible sources of pellets in the environment and propose mitigation strategies to improve the situation.

The urbanized characteristics of the coast of Salvador do not seem to favor long-term deposition of pellets on sandy beaches, because along various sectors of the coast the area that should correspond to the backshore is replaced by walls that support the beachside avenue. However, the absence of a well-developed backshore did not seem to be a determinant factor for pellet deposition – at least recent deposition –, considering that sites such as P12 (Jardim dos Namorados beach) presented a high concentration of pellets during the winter, despite the anthropogenic obstacle (wall) being within reach of high water swash. At sites such as P14 (Jardim de Allah beach) and P15 (Aeroclube beach) which contain a wider sand strip and a better developed vegetated backshore, characteristics that are theoretically more favorable for deposition, the PPI was very low and low (winter and summer, respectively), whereas other sites with the same characteristics (e.g. P16 – Boca do Rio beach) presented higher concentrations.

The difference between classifications is most likely a reflex of a number of factors. However, as reported by Turra *et al.* (2014), pellet distribution patterns on sandy beaches appear to be more related to oceanographic processes than anthropogenic processes. Therefore, it is reasonable to infer that the characteristics of each season and beach, such as the presence of a well-developed backshore and the exposure to waves, alter the transport

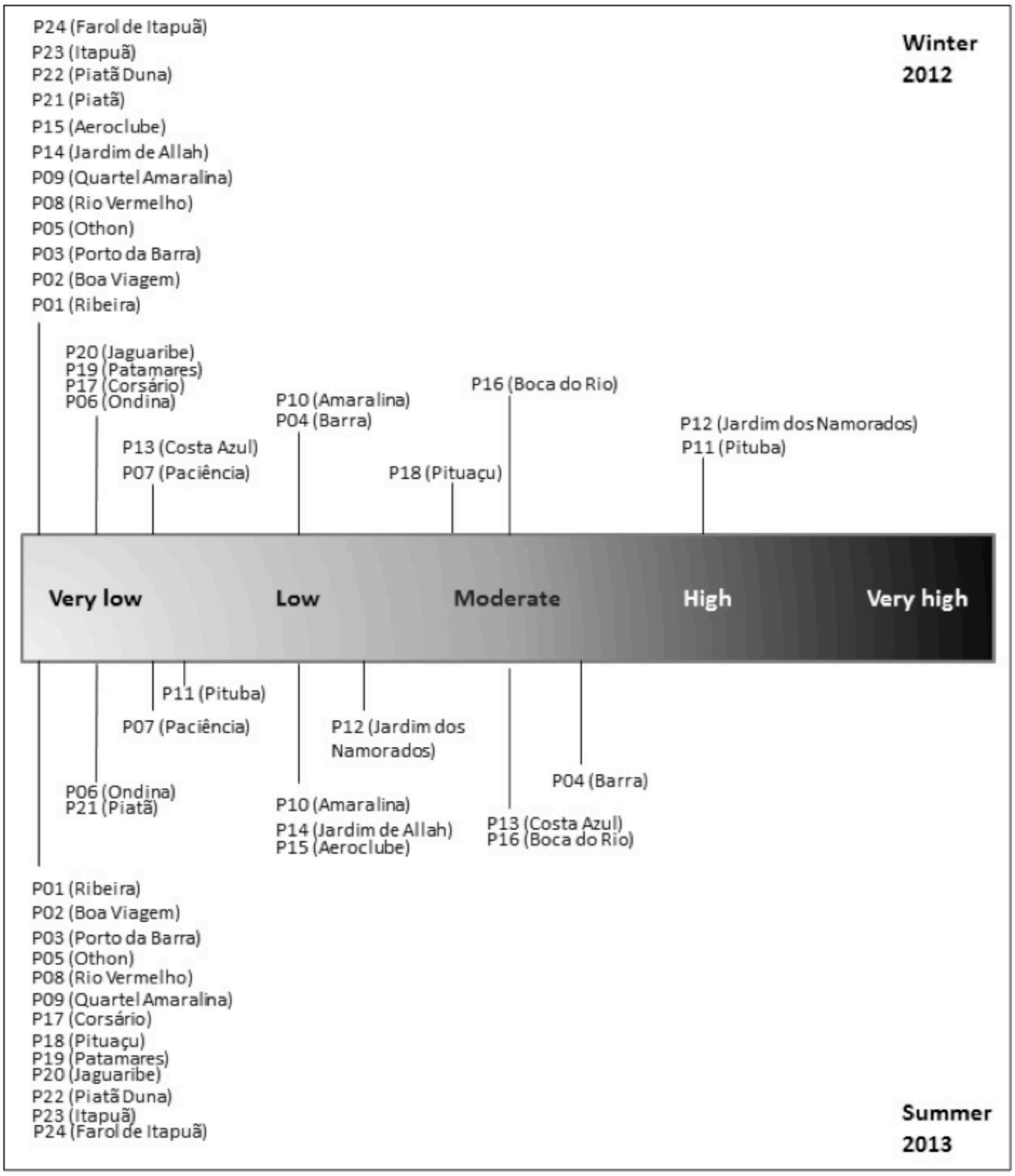

Figure 2 - Pellet Pollution Index (PPI) for 24 beaches in the municipality of Salvador during the winter of 2012 and summer of 2013.

Figura 2 - Índice de Poluição por Pellets (PPI) em 24 praias do município de Salvador durante o inverno de 2012 e verão de 2013.

and deposition patterns of pellets along the coast of Salvador, thus influencing the degree of pollution by this plastic item. Another important factor to be considered is the fact that, due to the low density of pellets (usually composed by PP and PE) and their small size, high-energy events such as storms can remobilize them and send them floating back to the surf zone or open water. In this situation, hydrodynamic factors may redistribute them along the same shoreline or strand them on a beach located far from their origin.

4. Conclusions

The coast of Salvador is polluted by plastic pellets to higher and lower degrees. The results determined through the use of the Pellet Pollution Index seem to reflect the reality experienced in the field, where beaches with a great number of pellets visible to the naked eye presented a higher PPI. The very low degree of pellet pollution on the beaches located within the TSB (P01 – Ribeira beach and P02 – Boa Viagem beach) during both seasons allows a reasonable inference that the port of Salvador is probably not a relevant source of pellets to the local marine environment. Although the majority of industries that use plastic pellets are also located near sites P01 and P02 they do not seem to be local sources of pellets for the sites. However, eventual pellets spills or inappropriate disposal in the sewage system could carry pellets to farther beaches.

Detailed information concerning sewage/drainage system are important in order to identify areas of greater

Table 2 - Use of the Pellet Pollution Index (PPI) in various studies. Number of rows for each study represents the number of sampling sites.

Tabela 2 - Uso do Índice de Poluição por Pellets (PPI) em vários estudos. O número de linhas em cada estudo representa o número de pontos/locais de amostragem.

Author(s)	Study area	Density (pellets/m²)	PPI	Classification
Costa *et al.*, 2010	Brazil	222.22	4.44	Very High
		44.44	0.89	Low
		100.00	2.00	Moderate
D'Antônio *et al.*, 2012	Brazil	262.22	5.24	Very High
		1636.67	32.73	Very High
		146.67	2.93	High
		351.11	7.02	Very High
		906.67	18.13	Very High
		95.56	1.91	Moderate
Gomes, 1973	Brazil	31.75	0.64	Low
Lima, 2012	Brazil	154.00	3.08	Very High
		505.00	10.10	Very High
		281.00	5.62	Very High
		103.00	2.06	High
		63.00	1.26	Moderate
		95.00	1.90	Moderate
		383.00	7.66	Very High
		270.00	5.40	Very High
		84.00	1.68	Moderate
		48.00	0.96	Low
Manzano, 2009	Brazil	5.00	0.10	Very Low
		15.00	0.30	Very Low
		2.00	0.04	Very Low
		8.00	0.16	Very Low
		3.00	0.06	Very Low
		58.00	1.16	Moderate
		0.80	0.02	Very Low
		15.00	0.30	Very Low
Turner and Holmes, 2011	Maltese Islands	0.70	0.01	Very Low
		167.00	3.34	Very High
Zbyszewski *et al.*,2014*	North America (Lake Erie)	0.36	0.01	Very Low
		0.02	0.00	Very Low
		0.24	0.00	Very Low
		0.00	0.00	Very Low
		0.03	0.00	Very Low
		0.39	0.01	Very Low
		0.90	0.02	Very Low
		2.03	0.04	Very Low
		1.00	0.02	Very Low
		0.60	0.01	Very Low

Table 2 - Use of the Pellet Pollution Index (PPI) in various studies. Number of rows for each study represents the number of sampling sites. (Cont.).

Tabela 2 - Uso do Índice de Poluição por Pellets (PPI) em vários estudos. O número de linhas em cada estudo representa o número de pontos/locais de amostragem. (Cont.).

Author(s)	Study area	Density (pellets/m²)	PPI	Classification
	North America (Lake St. Clair)	0.01	0.00	Very Low
		0.00	0.00	Very Low
		0.01	0.00	Very Low
		0.00	0.00	Very Low
		0.89	0.02	Very Low
	North America (Lake Huron)	33.23	0.66	Low
		1.47	0.03	Very Low
		0.57	0.01	Very Low
		0.14	0.00	Very Low
		0.00	0.00	Very Low
		0.00	0.00	Very Low
		0.00	0.00	Very Low

risk of pellet input into the environment, as well as to identify sources and allow for mitigation. Information regarding the characteristics of the material such as types of plastic resins (polyethylene and polypropylene, for example), as well as the main color of the pellets that nearby plastic industries use in their production processes, can be important in order to verify if the pellets found stranded on Salvador's beaches present the same characteristics.

Although Salvador presents highly urbanized beaches in which periodic cleaning activities are performed by the local government using mainly rakes, the presence of pellets on these beaches also suggests that the current cleaning methods are not effective in removing small items that increasingly accumulate on the sand. This raking is not performed thoroughly along the entire coast due to its extent and the limited number of cleaning agents involved. It usually focuses on short stretches of beach where macro marine litter accumulation can be spotted near touristic beaches. Generally, two or three people, who cover a long stretch of beach (approximately 2 km), perform this cleaning method. While one of these people roughly rakes the sand for large plastic items and gathers them in small piles, the remaining two people follow the first and collect the debris in plastic bags. In some cases, a tractor comes later to gather the bags, or the same people take the bags with them to the nearest garbage pick-up location. Due to the space between the teeth of the rakes (usually > 1 cm) this tool has little ability of removing pellets from the beach. On the other hand, the rakes can bury the pellets under a thin layer of sediment. However, because the methodology used in the present study consisted of sampling the superficial 5 cm of sediment, this factor was minimized.

Analyzing the composition, size and characteristics of marine litter is important to understand the significance of its presence in the environment and, consequently, the threats imposed by it. The PPI proved to be a useful and easily applicable tool with great potential in evaluating and monitoring the level of pollution by pellets on the surface of sandy beaches. The use of the PPI seemed to be suitable for other places around the globe, aiding in the comparison of results, which can be difficult due to lack of standardization. Moreover, the index can be a useful tool to assess the environmental quality of beaches, indicating the degree of pollution by plastic pellets.

Such information could help future attempts of removing the anthropogenic plastic component from beach sediments and other marine environments.

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Design and evaluation of marine and coastal governance indicators for the Southern Mexican region*

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ABSTRACT

This paper presents a set of coastal and marine governance indicators for the southern Mexican coast; this set of indicators was developed as a part of the database, information and knowledge provision for the Regional and Marine Planning Process for six -southern and central- Pacific coastal states (RMPP-SCP). The theoretical framework and methodological approach followed the concepts developed by the Intergovernmental Oceanographic Commission (IOC-UNESCO). The following three different spatial/administrative scales were used: regional, state and county levels. This paper mainly examined the county-level results. A total of forty-six indicators were created, evaluated and used to define four compound indexes related with the institutional, policy and legal arrangements; the adequacy of the management process; the information, knowledge and participation level and the mainstreaming of the planning proposals, finally, aggregating these four indexes one general governance index for the region was proposed. We explored the internal consistency of the indicators by running several uncertainty analyses that entailed evaluating the effect of the aggregation method, the weighted scheme and the exclusion of individual indicators in the overall performance of the study region and its four dimensions (goals). The general governance index shows only 9% (5/53) of the total counties with a regular/medium governance level and 91% (48/53) with poor/bad governance level. An interesting and expected finding was the observation of a significant correlation between the general governance index and the governmental poverty level index. Using the governance results, the paper proposes several paths to implement the RMPP-SCP actions at county or state level; identifies the key elements (i.e. indicators, objectives, goals) to work on them in order to have more chances of success in implementing the program, and the critical variables (related to governance) that need to be improved to maintain or improve the environmental quality of the region. The set of governance indicators could be applied to other regions in the country for promoting integrated coastal and marine planning and management, but also could provide practical benefits for the development of municipalities and states when using them as benchmarking strategies.

Keywords: Governance Indicators, Coastal, Marine, Planning Process, Mexico.

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RESUMO [§]

Concepção e avaliação de indicadores de governança marinhos e costeiros para a região sul do México

Este trabalho apresenta um conjunto de indicadores de governança costeiros e marinhos para a costa sul do México; este conjunto de indicadores foi desenvolvido como parte da base de dados, informação e conhecimento para o Processo de Planeamento Regional e Marinho em seis estados costeiros, meridionais e centrais, do Pacífico (RMPP-SCP). O referencial teórico e a abordagem metodológica seguiram os conceitos desenvolvidos pela Comissão Oceanográfica Intergovernamental (COI-UNESCO). Utilizaram-se as três escalas espaciais e administrativas seguintes: regional, estadual e municipal. Neste trabalho examinaram-se, principalmente, os resultados a nível municipal. No total, criaram-se, avaliaram-se e utilizaram-se quarenta e seis indicadores para definir quatro índices compostos, relacionados com a) arranjos institucionais, políticos e legais; b) com a adequação dos processos de gestão; c) com a informação, conhecimento e nível de participação; e d) com a integração das propostas de planeamento. Finalmente, estes quatro índices foram agregados por forma a propor um índice geral de governança para a região. A consistência interna dos indicadores foi testada através de várias análises de incerteza, o que implicou avaliar o efeito do método de agregação, o esquema ponderado e a exclusão de indicadores individuais no desempenho geral da região de estudo e as suas quatro dimensões (metas). O índice geral de governança revela que apenas 9% (5/53) do total de municípios apresentam um nível de governança regular / médio e que 91% (48/53) têm nível de governança baixo / mau. Um resultado interessante, ainda que esperado, foi a observação de uma correlação significativa entre o índice de governança geral e o índice governamental do nível de pobreza. Utilizando os resultados do índice de governança, propõem-se várias vias para implementar as acções RMPP-SCP a nível municipal ou estadual, identifica os elementos-chave (ou seja, indicadores, objectivos, metas) que devem ser considerados para ter mais hipóteses de sucesso na implementação do programa, e distingue as variáveis críticas (relacionadas com a governança) que precisam ser melhorados para manter ou melhorar a qualidade ambiental da região. O conjunto de indicadores de governança poderá ser aplicado a outras regiões do país para promover o planeamento e a gestão costeira e marinha integrada, mas também pode fornecer benefícios práticos para o desenvolvimento dos municípios e estados ao utilizá-los como estratégias de aferição.

Palavras-chave*: Indicadores de Governança, Costeiros, Marinhos, Processo de Planeamento, México.*

1. Introduction

One of the seven critical issues defined in Rio+20 conference summit was the importance of the world´s oceans as a key resource for a sustainable future. In regards to sustainable development goals, one of the conference outcomes established "that progress towards the achievement of the goals needs to be assessed and accompanied by targets and indicators, while taking into account different national circumstances, capacities and levels of development" (UN, 2012).

According to the Organization for Economic Co-Operation and Development (OECD, 1993), an indicator can be defined as a parameter or a value derived from other parameters that provide information about a phenomenon. The indicator has significance that extends beyond the properties directly associated with the parameter value. Indicators possess a synthetic meaning and reduce the number of measurements required to present a situation, simplify the process of communicating with users and are developed for a specific purpose. Importantly, an indicator, as a piece of information, is a part of a specific management process and can be compared with the objectives of that management process (Bossel, 1999).

Integrated coastal and marine management plans (Cicin-Sain & Knecht, 1998), coastal spatial planning (Kay & Alder, 2005), natural protected area establishment or monitoring (Marques *et al.,* 2013), regional sea studies (van Tatenhove, 2013) and Large Marine Ecosystems (LME) analysis (Sherman, 2013) require indicators and reporting technics that reflect the state of the environment, the impact of anthropogenic activities and the performance of the proposed actions, plans and programs among other scientific tools and administrative managerial instruments (Olsen, 2003; Belfiore *et al*., 2003; Pomeroy *et al*., 2005; Arceo & Granados-Barba, 2010).

The use of indicators in the coastal/marine arena goes back to the 90s with the frameworks provided by GESAMP (1995, 1996), Pacheco (1995), Garcia (1996), Burbridge (1997), Olsen *et al*. (1997) and Vandermeulen (1998), among others. These frameworks visualize the use of technical tools as a generalized process to assess environmental health and human development trends in marine/coastal areas. Most recently, international indexes and indicators, such as the Global Map of Human Impact on Marine Ecosystems, the Ocean Health Index (Halpern, *et al*., 2008, 2012) or the Global Coastal Network (Malone *et al*., 2014) have been developed.

In Mexico, the ministry of environment and natural resources (SEMARNAT) presents several coastal and marine indicators on the national level (SNIA-SEMARNAT), mostly focused on fisheries, oil process,

[§] Portuguese versions of the abstract and captions by Ana Gomes on behalf of the Editorial Board tourism, coastal population growth and coral reef behavior, on a yearly basis. Additionally, several integrated assessments and indicators have been developed in the context of the Regional and Marine Planning Processes of the country such as the Gulf of California, Gulf of Mexico and Caribbean Sea, North Pacific and Central and Southern Pacific (SEMARNAT, 2012) and also in international projects on the marine spatial planning of large marine ecosystems (Díaz-de-León & Díaz-Mondragón, 2013).

At the county level, Seingier *et al* (2010, 2011) created a "sustainability capacity index" and a "coastal orientation" index to assess the state of all the coastal municipalities in the country, and Poncela *et al* (2012) evaluated a modified human development index through the analysis of local Agenda 21 results for several coastal counties. In the context of climate change, a general framework for the construction of indicators and indices as well a proposed set of them were provided by the National Integrated Coastal and Marine Management Network (Azuz-Adeath *et al*., 2010 a, b), and for the Caribbean area, some indicators were presented for the National Program for Climate Change Adaptation in Natural Protected Areas (March *et al*., 2011).

According to Ehler (2003), in the field of integrated coastal management, coastal governance can be defined as the structures and processes used to govern behavior, both public and private, in the coastal area and the resources and activities it contains. Additionally, from the perspective of ecosystem-based management, the use of governance concepts and practices is essential to structure interventions in large marine ecosystems and to build agreements between parties (Duda & Sherman, 2002; Mahon *et al.,* 2009; Díaz-de-León & Díaz-Mondragón, 2013). Governance involves setting priorities that may establish hierarchies of interests, but the basis is recognition of what is excluded, as well as what is given priority in certain situations, through public participation and the involving of networks, stakeholders and actors (Sutherland & Nichols, 2006; Hoefnagel *et al*., 2013). In these situations, governance indicators may be the right tool to define baselines, evaluate variables and data availability and, monitor processes and achievements.

Coastal and marine governance play a key role in the success of any integrated coastal/marine management plan. Around the world, several coastal and marine indicators that include some type of governance component have been analyzed or applied; in Europe and Northern Africa (Smeets & Weterings ,1999; Baan *et al*., 2003; Sardá *et al.,* 2005; Ernoul, 2010; House & Phillips, 2012); in North and South America (Vandermeulen, 1998; Fontalvo-Herazo et al., 2007); Day and Dobbs (2013) in Australia and Cabral *et al*. (2013) and Ye *et al*. (2014) in Asia, among many others. Incorporating elements of governance identified by Ehler (2003), Belfiore *et al*. (2006) and Silva *et al*. (2011), the definition of governance that guides this study includes laws, policies, institutions and processes, working in an articulate way towards the proposal, implementation and monitoring of actions affecting social, economic and natural capital in the marine and coastal spaces.

The main objective of this paper is to present and analyses the performance of a set of 46 governance indicators developed for the assessment of the baseline conditions (characterization and diagnosis) in central and southern Mexico´s Pacific states and coastal counties as a part of the technical work developed for the Regional and Marine Planning Process (RMPP-CSP) conducted and headed by the Mexican Ministry of Natural Resources (SEMARNAT). Associated with the RMPP-CSP goals, four compound indicators were built to obtain a general or global governance index. In the following section, a description of the study area and the legal framework that supports the planning process will be presented. In the methodology section, we present the structure of the indicators and indexes proposed and evaluated. Finally, we show the results obtained in the assessment process for the coastal-marine governance level in 53 littoral counties and 6 coastal states.

1.1. Study Area and Legal Framework

The central and southern Mexican Pacific region comprises 6 coastal states with a terrestrial surface of 373,570km^2, and 53 coastal counties (shown in parentheses for each state), Jalisco (5), Colima (3), Michoacán (3), Guerrero (13), Oaxaca (20) and Chiapas (9); a marine component of 1,206,710 km^2 and a total coast length of 2,077 km (see Fig 1).

The total population in the region is 24,339,584 inhabitants (INEGI, 2010), which corresponds to 21.6% of the national population. In terms of poverty levels (Estrada *et al.,* 2011), Jalisco and Colima have low levels, Michoacán has a high level, and Guerrero, Oaxaca and Chiapas, the 3 poorest states in Mexico, have very high poverty levels.

The region contributes only 14% of the national Gross Domestic Product (GDP). The main economic activities are as follows: industry and commerce (Jalisco), tourism (Guerrero, Oaxaca and Chiapas) and agriculture (Michoacán and Jalisco), and three important ports are located in Colima, Guerrero and Chiapas. In general, the natural capital and biodiversity of the study area could be considered one of the biggest in Mexico; the highest numbers of several species in the country (pteridophytes, gymnosperms, angiosperms, amphibious, reptiles, birds and mammals) are located in the region (SEMARNAT, 2014a); the largest densities of endemic species occurred in the study area (Koleff & Soberón, 2008) and three of seven terrestrial ecoregions of

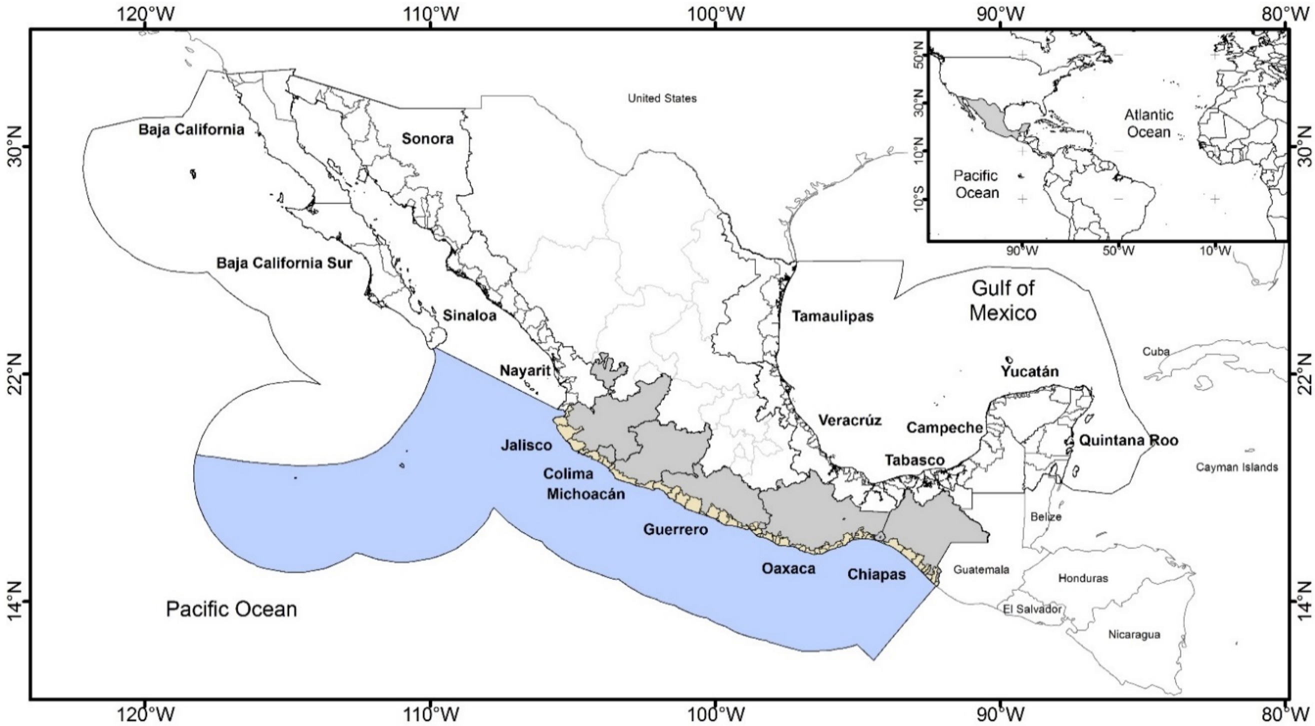

Figure 1 - Study area. Mexico's central and southern Pacific coastal states (gray) and coastal counties (light gray).

Figura 1 – Área de estudo. Estados do México central e sul na costa do Pacífico (cinzento) e municípios costeiros (cinzento claro).

Mexico could be observed (INEGI-CONABIO-INE, 2008). Several recreational beaches recognized worldwide are located in the area, including Costa Alegre (Jalisco), Manzanillo (Colima), Acapulco and Zihuatanejo (Guerrero) and Huatulco bay (Oaxaca), but the region is highly vulnerable to natural phenomena as earthquakes, hurricanes and landslides (SEGOB, SMN).

From a legal and regulatory perspective, marine and coastal areas of Mexico are extremely complex to manage given the diversity of sectoral policy instruments that apply to them. The most important coordination efforts have been taken from the bodies responsible for environmental issues. Recently the National Policy for Seas and Coast (CIMARES, 2012) and the Environmental Policy for Oceans and Coast (SEMARNAT, 2006a) -both instruments defined as a public policies-established the basis for the coastal management in Mexico, but until now, the country does not have any mandatory law created specifically for the coastal zone and its management. In the absence of a coastal law or legally defined integrated coastal zone management guidelines, the government and the scientific community have had to resort to the closest related existing instruments to assure coastal and marine sustainability, in this case the spatial planning processes.

The legal basis for the development of any type of territorial land use and planning in Mexico is established in the General Law for the Ecological Equilibrium and Environment Protection (LGEEPA, 1988). This law defines four types of territorial planning processes: general (for all the national territory), regional (developed by one or more states), local (developed at the county level) and marine (which includes the coastal zone). Any spatial planning process in Mexico must have four steps: characterization, diagnosis, prospective and proposal.

The National Strategy for Land and Sea Planning in Oceans and Coasts (SEMARNAT, 2006b) presented a framework for the development of the marine and coastal planning in different regions of Mexico including the Gulf of California, the Gulf of Mexico and the Caribbean Sea, the Northern Pacific and the Central and Southern Pacific. In all these processes, the central government developed the programs in collaboration with the coastal states and municipalities with strong public participation. At present, the first two programs mentioned are officially decreed and published in the Official Journal of the Federation and the last two are still in process of formulation.

The RMPP-SCP will be a regulatory instrument that will provide:

a) Regional coordination (6 coastal states), understanding and agreement about issues that should be addressed;

b) Enhanced coordination among Federal, State, Municipalities, participatory bodies, and stakeholders on ocean and coastal issues;

c) An instrument to guide and coordinate the Federal, State and County actions in the region;

d) A participatory arena for acquiring and sharing data and information to help avoid and reduce conflicts.

2. Methodology

The Regional and Marine Planning Process for the Southern and Central Pacific coastal states in Mexico (RMPP-SCP) uses the following four types of descriptive indicators: a) ecological, b) social, c) economic and d) governance in the evaluation process of the baseline of the study area using administrative limits at three resolution scales, regional, state and county.

The set of governance indicators presented in this paper was developed as a part of the database, information and knowledge delivery for the RMPP-SCP. All of the indicators and compound indices were mapped in a geographic information system (GIS) to show the preliminary results in public and sectorial participation forums before the integration of the final document. This section is focused only on the methodological process followed in the construction and evaluation of the governance indicators; includes the followed conceptual framework, information about the used data, the variables evaluation procedures, the aggregation and visualization methods, a general description of the proposed governance indicators and information about the internal consistency tests. Figure 2 shows the general steps scheme on the governance indicators structure.

The study region presents insufficiencies in coastal and marine technical information and data availability in comparison with other regions in the country. This fact imposed practical restrictions on the conceptualization, development and assessment of the indicators. Considering these restrictions, some general principles used in the definition of the governance indicators were as follows:

a) Ability to represent the goal and objective for which the indicator was developed in the context of the regional and marine planning process.

b) Availability of official information at county level.

c) Potential for monitoring through time and sensitivity to reflect changes in the governance status.

We must note that during the data acquisition process, political elections were taking place in several states, and some official web pages were not available due to legal regulations, limiting the availability of public information. In these cases, the information and data came directly from the environmental ministry.

Additionally, without any other similar studies working from the municipal to the regional scale, related to marine or coastal governance issues, the performance of the indicators were indirectly contrasted with the official poverty indicators (Estrada *et al.*, 2011), which include health, income, services and educational variables

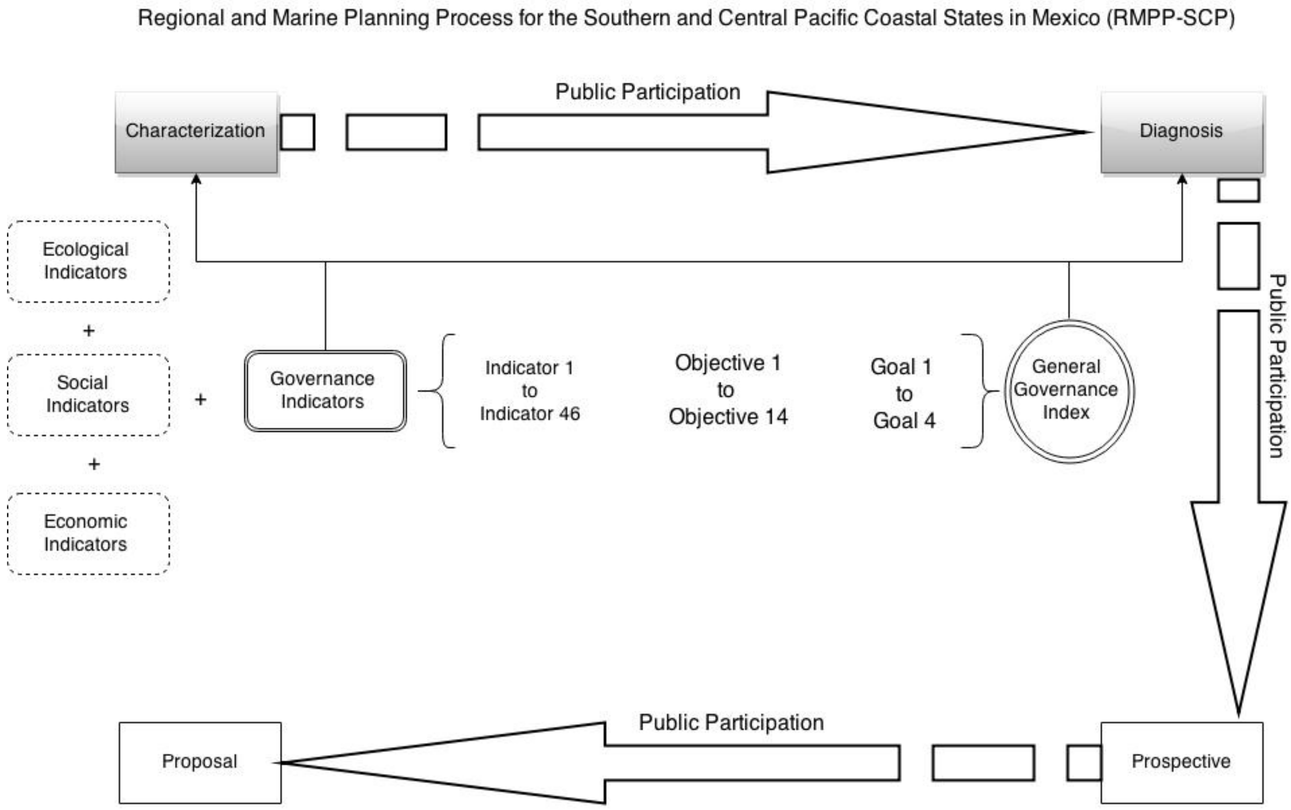

Figure 2 - General scheme of the Regional and Marine Planning Process. The types of indicators used in the characterization and diagnosis stages are presented with especial focus on governance indicators.

Figura 2 – Esquema geral do Processo de Planeamento Regional e Marinho. Os tipos de indicadores utilizados nas fases de caracterização e diagnóstico são apresentados com um enfoque especial nos indicadores de governança.

under the assumption that higher governance level means better living conditions. Several variables used to build the poverty indicators (Estrada *et al.*, 2011) include elements related with adapted spaces such as cities (e.g. towns with less than 5000 inhabitants), energy and clean water networks (e.g. inhabitants without access to electricity or clean water), and sewage systems (e.g. inhabitants without sewage systems). Furthermore, in order to examine whether the general governance index or its components related to broader measures of coastal and marine health and sustainability, some comparisons with the rate of vegetation loss, mangrove extension, soil degradation and fisheries status were performed for the study region at state level.

2.1. Conceptual framework

Several frameworks and guidelines of relevance to integrated coastal zone management have been proposed; the chapter 17 of "Agenda 21" (UN, 1992), the OECD integrated policies for coastal zone management (OECD, 1993), the World Bank guidelines for integrated coastal zone management (Post & Lundin, 1996), the European code of conduct for coastal zones (EU, 1999), the integrated marine and coastal area management guidelines (CBD, 2004) among others (see Belfiore *et al*., 2003; 2006).

This study follows the conceptual framework and methodology proposed by the Intergovernmental Oceanographic Commission (IOC-UNESCO) originally established for measuring the progress and outcomes of Integrated Coastal and Ocean Management (Belfiore *et al*., 2006), but in this research, adapted for a planning process in the Mexican context (e.g. Governmental levels; administrative jurisdictions; legal, regulatory and normative frameworks; participatory bodies and official committees) specifically to obtain governance baseline information as an input for the RMPP-SCP. The use of this framework was defined directly by the Mexican Ministry of Environment.

According to Bossel (1999) indicator sets about a given system are determined by two distinct requirements: (1) they have to provide vital information providing a picture about the current state and corresponding viability of that system; and (2) they have to provide sufficient information about the system´s contribution to the performance of other systems that depend on them. This study describe only the baseline or current governance state for the southern and central Pacific Mexican coast as an input for their regional and marine planning process.

Four goals and fourteen objectives were proposed in this study to build forty-six governance indicators. For every coastal county in the region the indicator´s variables were measured, grouped by objective, then by goal and finally aggregated to form the general governance index for the study region. All variables, indicators and indices obtained in each municipality were standardized so that the scores were between 0 and 1, where 0 corresponded to the worst conditions and 1 to the highest standards of governance. With all values ranging from 0 to 1, a qualitative scale was proposed: "low governance level" (values between 0 to 0.3333), "medium governance level" (values between 0.3334 to 0.6666) and "high governance level" (values between 0.6667 and 1). Table I shows the goals, objectives and number of indicators used in this research.

2.2. Database, evaluation, aggregation and visualization techniques

The main sources of information and data for the evaluation of the governance indicators were official public sources at the national (federal) level, from the official state and county web pages (if they exist) and through official journals of the federation, states and counties in which the laws and regulations were published.

When working with governance, some variables need to be evaluated in a qualitative way. In this study we used the following types of variables:

a) Dichotomous variables. These variables need to be evaluated by selecting between two alternatives like Yes/No or Exist /Not Exist, etc.
b) Qualitative variables. The options for this type of variable are wider than in dichotomous variables, but the elements under assessment remain qualitative, like Good/Regular/Bad or Started/In Development/Finished, etc.
c) Quantitative variables. These variables use integer numbers (discrete variables), fractional numbers (continuum variables), percentages, ratios, etc.

The following symbols will be used in the indicators tables: "Y/N" for dichotomous variables, "QV" for qualitative variables and "#" for quantitative variables.

In the indicator-building process, the dichotomous variables take the value of 1 or 0; the possible values for qualitative variables are 0, 1/4, 2/4, 3/4 or 4/4, and the direct scores obtained from quantitative variables were standardize between 0 and 1 based on the following formula: standardized variable=(original variable–minimum value) / (maximum value-minimum value).

In the aggregation process (Nardo *et al*., 2005; OECD, 2008), every group of indicators (grouped according to the corresponding goal) was averaged over all counties with the same weight for each indicator (linear aggregation), and the general governance index was calculated as the mean of the four values associated with each goal. The indicators were developed with a "positive"vision, which means that high values of the indicators are associated with better conditions. When several

Table I – Summary of governance goals, objectives and total number of indicators defined for the RMPP-CSP.
Tabela I – Resumo das metas de governança, objectivos e número total de indicadores definidos para o RMPP-CSP.

Goal	Objectives	Number of Indicators for each objective
1. Ensuring adequate institutional, policy and legal arrangements	1.1 Ensuring the coordination and coherence of administrative actors and policies	4
	1.2 Existence of adequate legislation and regulation	1
	1.3 Existence of environmental assessment procedures	4
	1.4 Existence of conflict-solving and law enforcement mechanisms	4
2. Ensuring adequate management processes and implementation	2.1 Managing coastal and marine issues through adequate planning instruments	4
	2.2 Implementing and enforcing the actions derived from the planning instruments	4
	2.3 Routinely monitoring and evaluating the planning instruments outcomes	4
	2.4 Supporting economic and administrative structures	2
3. Enhancing information, knowledge, awareness and participation	3.1 Ensuring the use of scientific and technical information for decision-making	3
	3.2 Ensuring sustained support from engaged stakeholders	4
	3.3 Ensuring Non-Governmental Organizations (NGO´s) involvement	1
	3.4 Ensuring adequate capacitation for the personnel involved	4
4. Mainstreaming the proposals and the economic instruments	4.1 Enabling and support the planning process through environmentally-friendly technology	3
	4.2 Incorporating economic instruments into coastal and marine management	4

years of information were available, and the information provided by the accumulation of values was more appropriate to establish the current conditions, the indicators use the aggregated value of the time series. To visualize the results, a GIS system was developed, and the indicators values and qualitative governance levels were mapped for each one of the indicators and goals at county scale (see supporting information SI.2 to SI.5).

2.3. Governance indicators

The set of governance indicators proposed in this study can be understood as a series of elements that determine the state of the region under analysis before implementing the spatial planning program (RMPP-SCP). These indicators establish the baseline for monitoring future efforts and should be understood according to the classification of Ehler (2003) as input-based rather than outcome-based indicators. Besides the framework used (Belfiore *et al*., 2006), recently other studies have proposed similar indicator measurements systems (Garces *et al*., 2013; Schernewski *et al*., 2014; Ye *et al*., 2014).

Table II presents the set of indicators developed and measured for each goal: goal 1 – "Ensuring adequate institutional, policy and legal arrangements"; goal 2 – "Ensuring adequate management processes and implementation"; goal 3 – "Enhancing information, knowledge, awareness and participation"; goal 4 – "Mainstreaming the ordinance proposals and economic instruments".

To "Ensuring adequate institutional, policy and legal arrangements" for the RMPP-SCP, this study proposed 13 indicators related with: the legal support at regional and county level; existence of institutional elements like official networks and governmental commissions; planning instruments and law enforcement mechanisms. To clarify the logic behind the inclusion of some indicators an example is presented.

In order to attain the goal 1, four objectives were proposed (see Table I); looking at the objective 1.3 "Existence of environmental impact assessment procedures", four indicators were measured (see Table II), one of them has a direct meaning "projects authorized through Environmental Impact Assessment" (1.3.2), the other three can be seen as a complementary tools; specifically the indicator "county surface with mangrove" (1.3.3) is related with objective 1.3 because mangrove is a federal protected species and any kind of development is prohibited in these areas.

The goal 2 "Ensuring adequate management processes and implementation" in the RMPP-SCP has been characterized by the evaluation of 14 proposed indicators (see Table II). Some indicators are related with development and planning programs at county and state level; existence of protected areas; availability of information and monitoring elements and local economic instruments for the implementation stage, such as indicator "existence of county income law" (2.4.1) which provides information on the formal mechanism through

Table II – The RMPP-CSP core indicator set: 4 goals, 14 objectives and 46 governance indicators.
Tabela II – Conjunto de indicadores para o RMPP-CSP: 4 metas, 14 objectivos e 46 indicadores de governança.

Goal	Objective	Indicator number, name and valuation method in parenthesis (QV=Qualitative Variable; #=Quantitative Variable; Y/N=Dichotomous Variable)
1.- Ensuring adequate institutional, policy and legal arrangements	1.1	1.1.1 County participation in local ecological planning process (QV)
		1.1.2 County participation in regional planning process (QV)
		1.1.3 Existence of relevant county commissions (e.g. ecology, territorial planning, water management, forestry, beaches management) (#)
		1.1.4 County participation in relevant associations or networks (e.g. coastal counties association, network for counties with ports) (Y/N)
	1.2	1.2.1 Relevant county legislation and regulations (e.g. territorial planning, environmental) (#)
	1.3	1.3.1 Existence of country regulations for wastewaters (Y/N)
		1.3.2 Projects authorized trough Environmental Impact Assessment (#)
		1.3.3 County surface with mangrove (as a protected species) (#)
		1.3.4 Bacteriological quality in county beaches and certificated beaches (#)
	1.4	1.4.1 Local land use planning process stage (i.e. without, started, technically finished, legally approved) (QV)
		1.4.2 Regional planning process stage (i.e. without, started, technically finished, legally approved) (QV)
		1.4.3 PROFEPA (Mexico´s Environmental Protection Agency) regular visits (#)
		1.4.4 PROFEPA (Mexico´s Environmental Protection Agency) specific inspections (#)
2.- Ensuring adequate management processes and implementation	2.1	2.1.1 Existence of county development plans (Y/N)
		2.1.2 Existence of local land use plans (legally approved) (Y/N)
		2.1.3 Existence of regional land use plans (legally approved) (Y/N)
		2.1.4 County surface under federal protection (#)
	2.2	2.2.1 Volume of wastewater treated in the county (#)
		2.2.2 Existence of "clean beaches" committees (Y/N)
		2.2.3 Existence of certified beaches (as a regulatory instrument) (Y/N)
		2.2.4 Existence of RAMSAR sites in the county (as a regulatory instrument) (Y/N)
	2.3	2.3.1 Existence of public GIS systems with county level information (Y/N)
		2.3.2 Existence of certified beaches (as a monitoring element) (Y/N)
		2.3.3 Existence of RAMSAR sites in the county (as a monitoring instrument) (Y/N)
		2.3.4 County surface under federal protection (as a monitoring instrument) (Y/N)
	2.4	2.4.1 Existence of county income law (potential to support managerial economic and administrative structures in the county) (Y/N)
		2.4.2 County expenditure per capita per county surface (potential to support managerial economic and administrative structures in the county) (#)
3.- Enhancing information, knowledge, awareness and participation	3.1	3.1.1 Universities and research centers in the county -marine related- as a scientific and technical providers (#)
		3.1.2 Research centers for fisheries in the county as a scientific and technical providers (#)
		3.1.3 Existence of risk plans for the county (Y/N)
	3.2	3.2.1 Members of the council for sustainable development in the county (#)
		3.2.2 Existence of relevant councils and commissions in the county administration (Y/N)
		3.2.3 Existence of official web page in the county (operating) (Y/N)
		3.2.4 Potential for public information access (#)
	3.3	3.3.1 Registered environmental related ONG´s in the county (#)

	3.4	3.4.1 Education commission in the county administration (#)
		3.4.2 Universities and research centers in the county -marine related- as a potential capacity building bodies (#)
		3.4.3 Research centers for fisheries in the county as a potential capacity building bodies (#)
		3.4.4 Existence of prevention of risk programs in the county (Y/N)
4.- Mainstreaming the proposals and the economic instruments	4.1	4.1.1 Number of Eolic power plants in the county (#)
		4.1.2 Number of hydroelectric power plants in the county (#)
		4.1.3 Beneficiaries from the energy saving program in aquaculture in the county (#)
	4.2	4.2.1 Payments from ecological services in the county (#)
		4.2.2 Beneficiaries from social programs (poverty eradication) in the county (#)
		4.2.3 Payments associated with coastal zone concessions in the county (#)
		4.2.4 Economic resources from the National Disasters Found applied in the county (#)

which financial resources could be applied to the RMPP-SCP at county level.

The goal 3 “Enhancing information, knowledge, awareness and participation”, has been evaluated using 12 indicators (see Table II) associated with the academic and research capacities in the region; NGO´s presence; participatory bodies and access to public information.

The most challenging goal in the indicator´s construction process was “Mainstreaming the planning proposals and economic instruments” since the original framework (Belfiore *et al*., 2006) has been developed for the assessment of operating Integrated Coastal Area Management plans. In the present study the indicators were used for the assessment of the baseline conditions (characterization and diagnosis) for the RMPP-SCP.

The goal 4 in this paper includes only two of the three objectives proposed originally by Belfiore *et al*. (2006), which were associated with the existence of environmentally-friendly technology and the incorporation of economic instruments into coastal and marine management. For this goal, 7 indicators were measured, 2 of them related with the operation of environmentally-friendly technology in the region and the rest of them have to do with economic programs currently running.

It is important to note that some indicators could be perceived as redundant, such as the use of "research centers for fisheries in the county". This indicator was used in the goal "Ensuring the use of scientific and technical information for decision-making" because we considered the research centers a natural technical information source, but we also use the same variable as a potential capacitating provider in the goal "Ensuring adequate capacitating for the personnel involved". In the future, these types of indicators need to be redefined. For example, at some point, the spatial planning program will be in its implementation phase and then we could not only measure the capacitating potential of the research centers but also have the opportunity to monitor the number of taught courses, the number of students by cohort or the number of graduates.

The detailed explanation of each indicator and the rationale behind its selection and construction, can be seen in Supporting Information SI.I.

2.4. Indicator’s scale sensitivity and internal consistency

Many environmental problems are characterized by complex and dynamic interdependencies across scales and levels (Termeer & Dewulf, 2014). The concept of scale as a basis for scale-sensitive governance was recently reviewed in theoretical form by Padt & Arts (2014) and in a practical manner by Schraad-Tischler (2014). In the field of environmental governance, traditionally two scales are used, spatial and temporal, but Cash *et al*. (2006) made an important contribution by identifying specific governance scales incorporating jurisdictional or administrative, institutional, management, knowledge and social networks and also outlining an interactions typology that includes cross-level, cross-scale, multilevel and multiscale interactions.

In this study, we followed the theoretical framework proposed by the Intergovernmental Oceanographic Commission (IOC-UNESCO), assuming that its quality has been tested and proven at the international, regional and national level (Belfiore *et al*., 2003; Belfiore *et al*., 2006; Souto, 2014). To assess the overall quality of the compound indicators or indexes proposed in this study, we analyzed the soundness of the procedures used in its construction by considering different weight and aggregation methods, modeling data error and excluding several indicators. The data standardization procedure Min-Max (0-1) was adopted as a political and technical decision at the launch of the study, and no further tests were performed.

Following Nardo *et al*. (2005), OECD (2008) and Charron (2010), we performed a sensitivity and uncertainty analysis to gauge the robustness and internal consistency of the composite indicators obtained. Two aggregation methods were tested, linear and geometric, as were two weighting schemes, equal weights and weights according the results of factor and principal component analysis and several tests on data exclusion using the 14 groups of indicators were performed.

3. Results

3.1. Efficiency and robustness of the indicators

As a first-order outcome, the proposed set of indicators, compound indexes and general governance index for the Mexico´s Southern and Central Pacific planning processes has been very suitable in the characterization and diagnostic stages. The model provides valuable information about the governance´s baseline and could be useful for monitoring the progress of the RMPP-SCP program during and after its implementation.

Indicators that can be used to map institutional, managerial, participatory and mainstreaming elements related to the RMPP-SCP have been defined at the county, state and regional levels through four analysis dimensions (goals) and fourteen indicator groups (objectives). In this way, the model could be useful in comparing sub-national and regional behavior.

Several test cases were performed to check the internal consistency of the indicator set. In all tested cases, the general governance index for the region remained at the same low qualitative level. We explore different aggregation and weighting schemes which include equal weighting, linear (LIN), geometric (GEO) and weighting according with factor analysis and principal component results (PCA); also we test the effect of exclusion one objective at time. The average relative error for all the tested cases was 7.7% (see Supporting Information SI.1). Using these results we adopt the linear aggregation method to build the general governance index and the compound indicators (for goals and objectives).

The greater difference between aggregation and weighting methods occurred when we used geometric aggregation with the equal-weight scheme. The highest sensitivity to data exclusion occurred when we removed the indicators related to the existence of a county income law and county expenditure per capita per county surface area. The lowest sensitivity to data exclusion appeared with the exclusion of indicators which describe the existence of universities, research centers (marine-related), research centers in fisheries and risk plans in the county (see Supporting Information SI.II).

3.2. Region-specific outputs

The region under analysis comprises 6 coastal states and 53 littoral counties. After the assessment of 46 governance indicators in each municipality, the results show a very low general governance level 0.1997 (0 to 1 scale). Only five counties present “medium” governance level in the general index.

Considering all the municipalities scores, the best conditions of governance are associated with goal 1 “Ensuring adequate institutional, policy and legal arrangements” (G=0.2649). To this goal, the most favorable conditions of governance are observed in objective 1.3 “Existence of environmental impact assessment procedures” (G=0.4233) wherein the indicator 1.3.2 “Projects authorized trough Environmental Impact Assessment” shows the highest score (G=0.8859), for this indicator 50 counties can be qualified with high levels of governance, reinforcing the fact that EIA is a well-established regulatory instrument in Mexico.

Looking at each goal, the lowest value of governance was obtained in goal 4 “Mainstreaming the ordinance proposals and the economic instruments” (G=0.1617), for which only one county presented medium qualifications; the rest of them presented low levels. For this goal, the lowest score comes from objective 4.1 “Enabling and support the planning process through environmental-friendly technology” (G=0.0377) in which the worst evaluated indicator was the “number of Eolic plants in the county” (G=0.0189). Only for goal 3, “Enhancing information, knowledge, awareness and participation” two municipalities present “high” values of governance, but the general average was (G=0.1708).

Figure 3 and supporting information SI.6, displays the behavior of general governance index, which shows the aggregate information of the four goals for every county in the study region.

The individual behavior of each county can be seen in Table III and supporting information SI.7. Only Manzanillo, in Colima state, presents values greater than 0.3333 for all the goals, which means that in general this county presents medium to high level of governance.

According with Charron *et al*. (2010) there is a general acceptance among scholars and policy-makers as to the crucial role of government institutions for the welfare of its citizens and also, good governance is seen as a necessary requirement for countries to foster economic development (Rothstein & Teorell, 2008) and environmental sustainability (Welsch, 2004; Morse, 2006). In this respect, by way of a comparative analysis, we used official information about the poverty level at county scale (Estrada *et al.*, 2011) to search for a relationship with the general governance index obtained by averaging the results for the four goals in each county. A significant, direct linear relationship (r=0.65) was found between the poverty level and the governance stage, indicating that better conditions in the county (low poverty) are associated with high levels of governance and vice versa (see Figure 4).

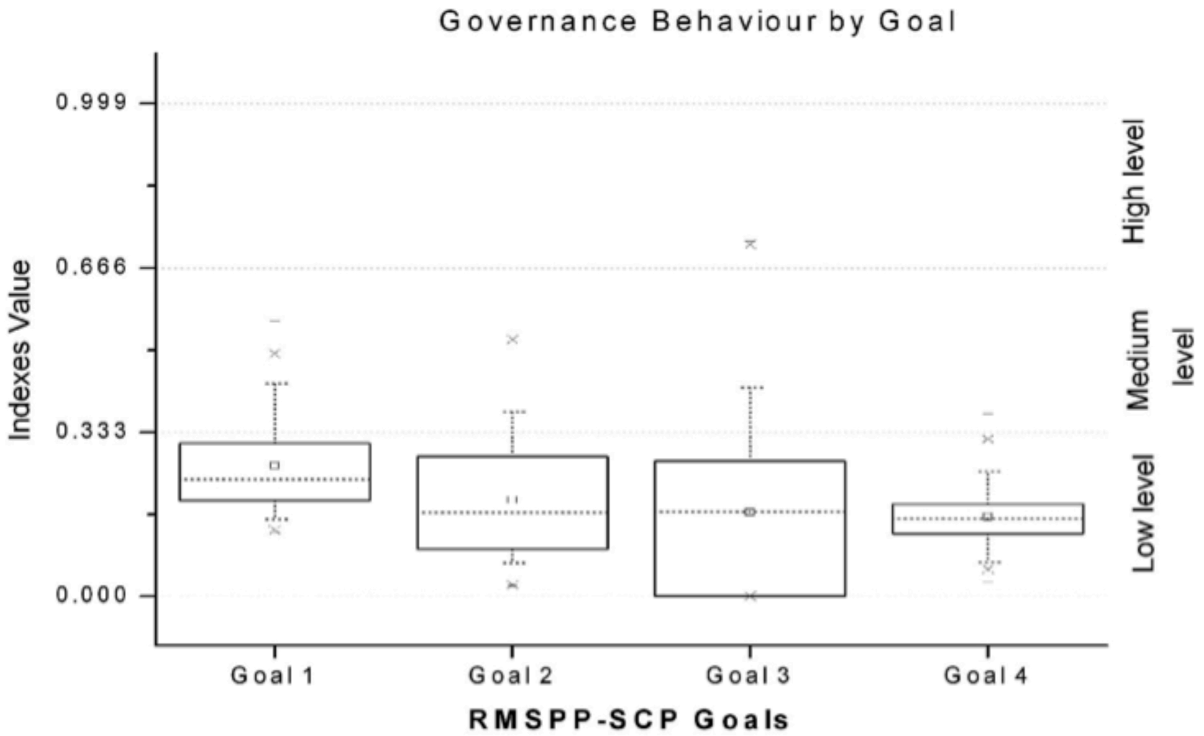

Figure 3 – Governance indicator performance for each goal, using all the coastal counties in the study region.

Figura 3 – Desempenho do indicador de governança para cada meta, usando todos os municípios costeiros na região de estudo.

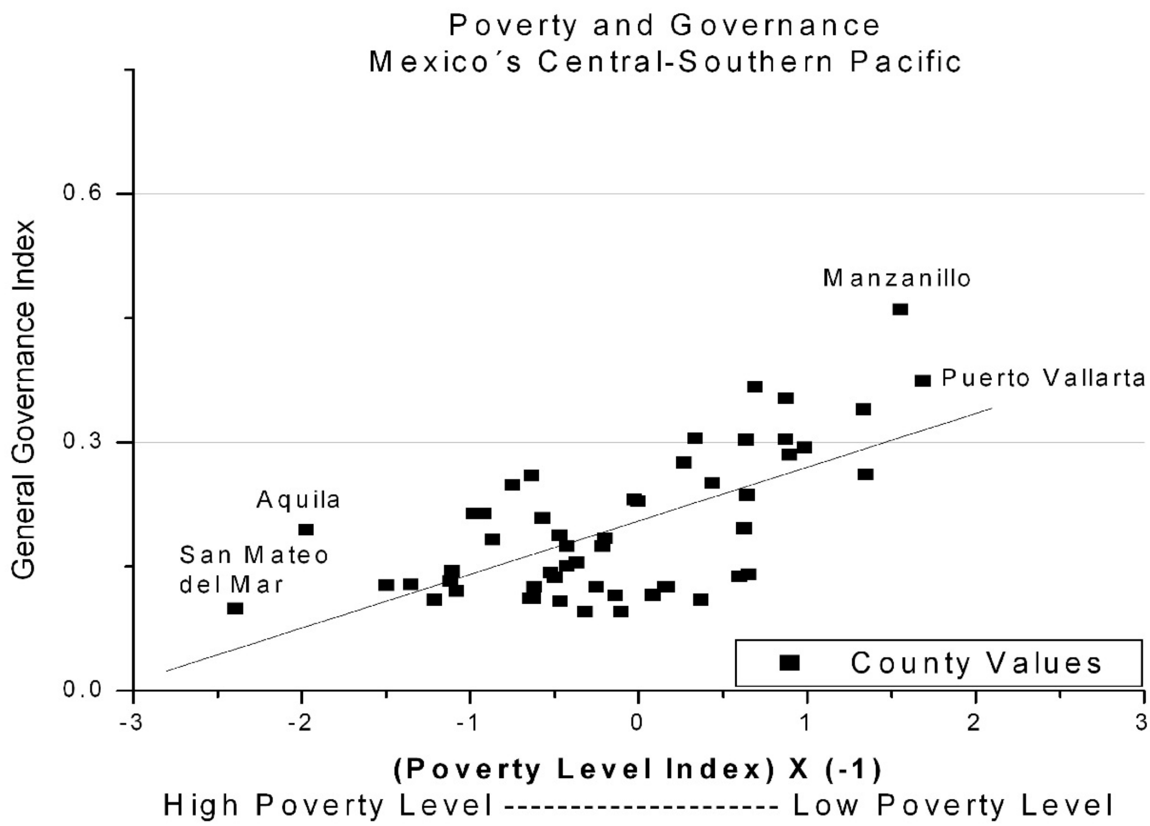

Figure 4 – Comparison between the global governance and poverty level for all the coastal counties in the study region.

Figura 4 – Comparação entre a governança global e o nível de pobreza para todos os municípios costeiros na região de estudo.

Table III – Summary of governance indicators assessment for the study region (0=lowest to 1=highest governance score).

Tabela III – Resumo da avaliação dos indicadores de governança para a região de estudo (0=menor a 1=maior pontuação de governação).

State	County	Goal 1	Goal 2	Goal 3	Goal 4	General
Jalisco	Puerto Vallarta	0.3853	0.5211	0.3731	0.2165	0.3740
	Cabo Corrientes	0.4005	0.3122	0.1948	0.1940	0.2754
	Tomatlán	0.4642	0.3619	0.2353	0.1573	0.3047
	La Huerta	0.3654	0.2430	0.1910	0.1463	0.2364
	Cihuatlán	0.4928	0.2211	0.3850	0.0753	0.2935
Colima	Manzanillo	0.3891	0.3681	0.7136	0.3708	0.4604
	Armería	0.4164	0.3239	0.4956	0.2309	0.3667
	Tecomán	0.3930	0.1638	0.4174	0.2401	0.3036
Michoacán	Coahuayana	0.2844	0.1994	0.0130	0.0557	0.1381
	Aquila	0.3208	0.2325	0.1000	0.1244	0.1944
	Lázaro Cárdenas	0.5590	0.3675	0.2430	0.1895	0.3398
Guerrero	La Unión de Isidoro Montes	0.1620	0.0227	0.0433	0.3193	0.1368
	Zihuatanejo de Azueta	0.3977	0.3739	0.3035	0.0644	0.2849
	Petatlán	0.2165	0.1051	0.0312	0.1094	0.1155
	Técpan de Galeana	0.2349	0.0966	0.2260	0.1411	0.1746
	Coyuca de Benítez	0.2830	0.2202	0.2816	0.2525	0.2593
	Acapulco de Juárez	0.3100	0.2826	0.7208	0.0992	0.3532
	Benito Juárez	0.2477	0.0692	0.0372	0.1491	0.1258
	San Marcos	0.2115	0.1455	0.3249	0.1751	0.2142
	Florencio Villarreal	0.1938	0.0918	0.2611	0.2045	0.1878
	Copala	0.1642	0.0752	0.0251	0.1682	0.1082
	Cuajinicuilapa	0.2431	0.1860	0.2580	0.1469	0.285
	Marquelia	0.1562	0.1732	0.2750	0.1318	0.1840
	Juchitán	0.1350	0.0212	0.2810	0.1402	0.1443
Oaxaca	Juchitán de Zaragoza	0.2165	0.0721	0.2555	0.2402	0.1961
	San Dionisio del Mar	0.1672	0.0741	0.1111	0.1768	0.1323
	San Francisco del Mar	0.1910	0.0680	0.0000	0.1868	0.1115
	Santo Domingo Tehuantepec	0.2057	0.1317	0.0000	0.1007	0.1095
	Santiago Pinotepa Nacional	0.1660	0.1346	0.0000	0.0831	0.0959
	Santiago Jamiltepec	0.1603	0.853	0.0000	0.1363	0.0955
	Santo Domingo Armenta	0.1474	0.0982	0.0000	0.1938	0.1098
	Salina Cruz	0.2995	0.2912	0.4236	0.0294	0.2609
	Santiago Tapextla	0.1583	0.2318	0.0000	0.1185	0.1271
	San Mateo del Mar	0.1303	0.0852	0.0000	0.1809	0.0991
	Santa Maria Huazolotitlán	0.1834	0.1011	0.0000	0.1603	0.1112
	Villa de Tututepec de Melchor Ocampo	0.2582	0.0255	0.2733	0.1400	0.1743
	San Pedro Huamelula	0.2780	0.0838	0.0000	0.1398	0.1254
	San Miguel del Puerto	0.2121	0.0956	0.0000	0.1740	0.1204
	Santiago Astata	0.2200	0.1133	0.0000	0.1270	0.1151
	San Pedro Mixtepec – Distr. 22	0.2211	0.1573	0.1111	0.0730	0.1406
	Santa María Huatulco	0.2738	0.5277	0.3409	0.0688	0.3028

	Santa María Colotepec	0.2262	0.1576	0.0000	0.1187	0.1256
	Santa María Tonameca	0.2542	0.0889	0.0000	0.1695	0.1281
	San Pedro Pochutla	0.2002	0.1543	0.1111	0.1358	0.1504
Chiapas	Tonalá	0.4315	0.2943	0.1715	0.2513	0.2871
	Pijijiapan	0.3699	0.2548	0.0000	0.1826	0.2018
	Mapastepec	0.2366	0.2098	0.0000	0.1728	0.1548
	Acapetahua	0.2567	0.2908	0.0000	0.1821	0.1824
	Villa Comaltitlán	0.2056	0.2745	0.1910	0.1856	0.2142
	Huixtla	0.2653	0.3225	0.1867	0.1403	0.2287
	Tapachula	0.2567	0.2033	0.2632	0.2798	0.2507
	Mazatán	0.2304	0.3994	0.1820	0.1803	0.2480
	Suchiate	0.1900	0.1701	0.0000	0.1419	0.1255

Due to lack of information for the region, it was difficult to examine whether the general governance index or its components related to broad measures of coastal and marine health and sustainability. To address this problem, some variables were used to define the environmental quality of the region: the rate of natural vegetation loss (1993 to 2011), soil degradation (2002 to 2010), mangrove areas (CONABIO, 2009), fisheries and aquaculture status (CONAPESCA, 2013) and bacteriological quality of the coastal waters (SEMARNAT, 2014b).

The highest value of the general governance index is given in the state of Colima; this state presents the largest fisheries catch and the second major mangrove density in the littoral zone on the region. The second state with the highest governance index is Jalisco in which the highest rate of soil conservation is presented. The lowest rate of natural vegetation conservation occurs in Oaxaca which is the state with the lower governance score. In the case of Michoacan, a state with “low governance level”, the worst environmental conditions are present. The relationships between governance level and environmental quality for all the states in the region can be observed as supporting information (SI.8).

Analyzing the state level behavior (Figure 5), Jalisco and Colima, the northern states in the region, present the highest values of governance (G=0.2968 and G=0.3769 respectively). The counties with the highest governance values are Puerto Vallarta in Jalisco and Manzanillo in Colima. The first is a tourist port while the second, in addition to tourism presents important fisheries. The lowest governance values can be found in Oaxaca and Guerrero (G=0.1416 and G=0.1921 respectively). In these states, Copala in Guerrero and Santiago Jamiltepec in Oaxaca were ranked with the lowest governance scores.

With exception of the State of Chiapas, in all other states in the region the highest governance values occur in municipalities with tourist or commercial ports; Puerto Vallarta in Jalisco, Manzanillo in Colima, Lazaro Cardenas in Michoacan, Acapulco in Guerrero and Santa Maria Huatulco in Oaxaca, showing a clear relationship between economic development and governance. The natural vegetation conservation for these counties is almost the same that the observed average for the region and the soil degradation was 8% below the regional mean.

The top 10% of counties with better governance conditions occur in Jalisco (2), Colima (2), Michoacán (1) and Guerrero (1). The bottom 10% of counties with poorest governance conditions takes place in Guerrero (1) and Oaxaca (5). Figure 6 displays the general results at county level

3.3. Elements for planning practice towards local to regional sustainability

How can the governance indicators improve the deploying strategies process for the RMPP-SCP? To answer this question we need to be clear about one of the most complex element in the decision-making process: if the success of the RMPP-SCP implementation depends on the governance level, is imperious improve its actual level, but with limited resources (money, time, capacities) the decision-maker need to choose between start the instrumentation process in the more or in the less developed places. In this sense, the indicators presented in this paper may be useful to allow analyzing critical planning paths, working from different scales (county, state and region) and using information from indicators, RMPP-SCP planning objectives and goals.

If we use the indicator results starting with the worst governance conditions, Oaxaca can be identified as the state with the lowest governance level in the region (G=0.1416). Inside Oaxaca, the minimum governance score was observed in the municipality of Santiago Jamiltepec (G=0.0955) in which the major problem was

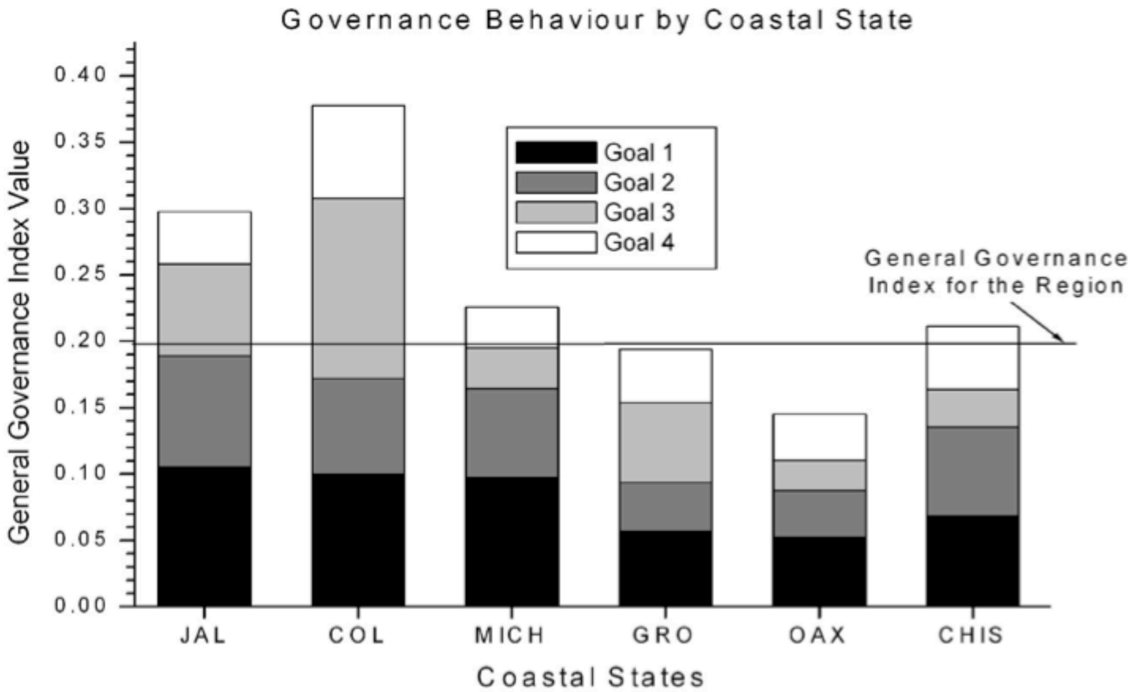

Figure 5 – Governance indicator performance by goal, for each coastal state in the study region.

Figura 5 – Desempenho do indicador de governança por meta, para cada estado costeiro na região de estudo.

detected in the goal 3 "Enhancing information, knowledge, awareness and participation"; all the indicators associated with this goal presented the lowest values. Of the 12 indicators defined within this goal, at least 3 or 4 can be assisted with the RMPP-SCP program to improve the governance of the municipality (e.g. the development of risk plans and risk prevention programs for the county, promoting linking actions with universities and research centers, supporting actions from NGO´s in the county).

In the other hand, if we apply the results to the top rated states, counties and attributes to maintain its general quality, the general governance index show Colima as the best evaluated state (G=0.3769) in order to improve its "medium" governance level, the RMPP-SCP program needs to work in goal 4 (the lowest dimension´s score for Colima), by example proposing Eolic farms areas in the state (the lowest scored indicator for the goal 4) or more specifically in Tecoman county, because is the last scored municipality in Colima.

Another approach for the use of governance indicators in the RMPP-SCP could be based in the environmental quality of the region. Using this approach a similar paradigm appears; the efforts and actions need starting in counties or states with good environmental quality or in places with degraded environment? Choosing any of the two options imply that the authorities need to define if they start to work with states or counties with high or low governance.

For the study region, in the best-case scenario path (i.e. good environmental quality and high governance level), the actions of the RMPP-SCP need to start in Chiapas (best environmental quality) and within Chiapas in Tonala municipality (highest general governance index G=0.2871).

The best governance score in Tonala occurs in the goal 1 "Ensuring adequate institutional, policy and legal arrangements" inside this dimension two indicators related to ecological and land use planning process presented the best evaluation, under these conditions is highly likely that the RMPP-SCP be successful by following this path. Following the worst-case scenario path (i.e. bad environmental quality and low governance level), the RMPP-SCP efforts and actions need to be focused in Michoacan State (poorest environmental quality) and within Michoacan in Coahuayana municipality (lowest general governance index G=0.1381). The lowest governance scores in Coahuayana were obtained in goals 3 and 4; in these two dimensions several indicators present the minimum qualification. The RMPP-SCP needs to apply continual efforts in this county and state to improve their governance and environmental quality.

4. Conclusions

The central and southern Mexican Pacific region is rich in natural resources, with a relatively unexploited coastal area, but with the highest levels of poverty in the country, coupled with a lack of scientific and technical capabilities. In this context, the possibility of implementing successful planning actions is based largely on the current status of their governance level. The pro-

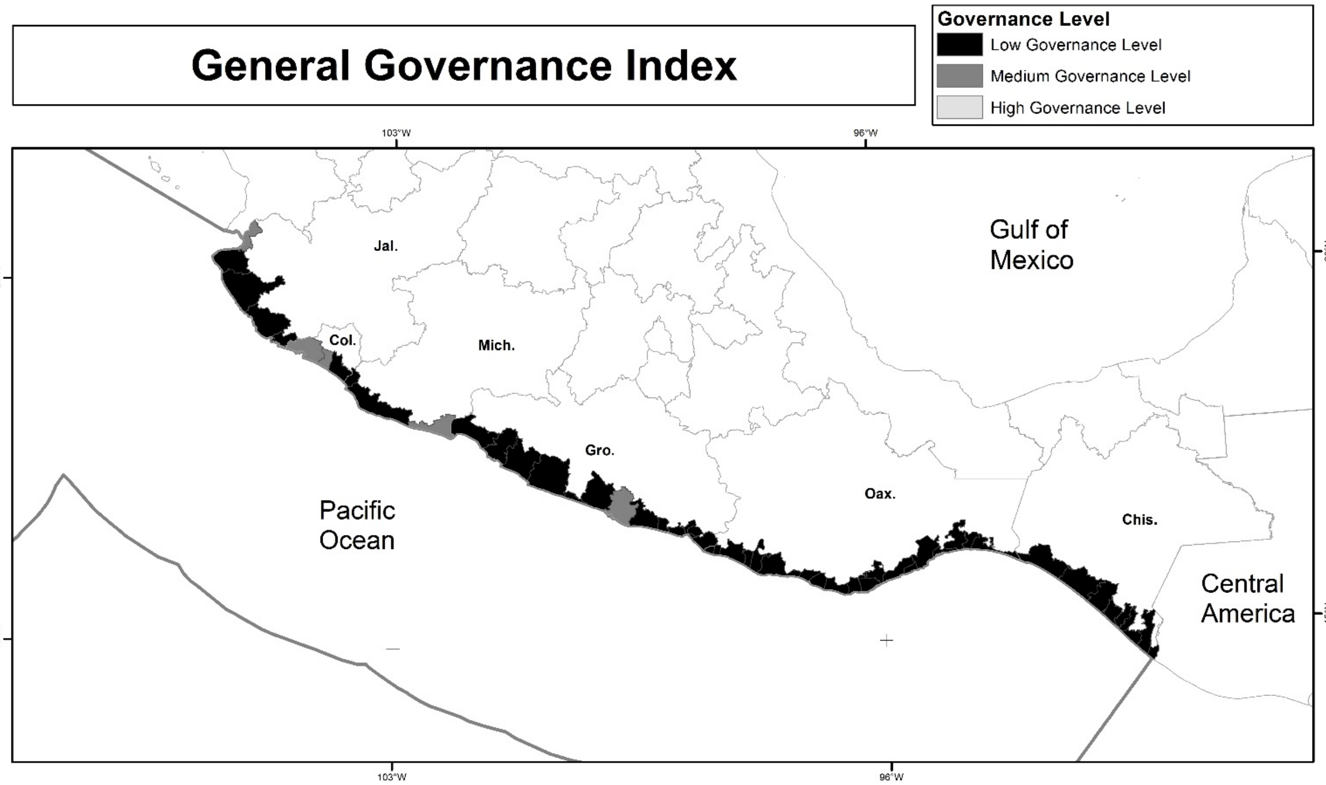

Figure 6 – Results from the general governance index, for each county in the study region.

Figura 6 – Resultados do índice geral de governança, para cada município na região de estudo.

posed set of indicators provides an overview of the conditions of governance and identifies the variables and indicators that should be improved in each county to succeed in the implementation of the RMPP-SCP objectives and goals.

A set of 46 governance indicators at county level were created and evaluated in the context of the RMPP-SCP following the framework proposed by the IOC-UNESCO (Belfiore *et al*., 2006) but adapted for the Mexican context in terms of variable selection, with good results. This study has proved that the proposed set of indicators is effective to establish the governance level of the study region, and states and coastal municipalities that comprise it. Of the six states that share the region just one presents medium or regular governance conditions and within the counties analyzed, only five has the same qualification (9%), the rest of states and counties can be characterized by poor governance conditions.

Internal consistency of the general governance index and their compound dimensions (goals) was checked using principal component analysis. The impact of the 4 goals and the 14 objectives on the overall index and the associated error was also evaluated. Sensitivity analysis suggested that the use of a linear aggregation scheme with equal weight was suitable for the general governance index evaluation after standardization of the indicator values (0-1). The validity of the governance index as an element to measure the coastal and marine health and sustainability was difficult to establish, due the lack of environmental information at county level. Using two of the available variables (i.e. natural vegetation cover and soil degradation) we can say that some of the counties located in the highest percentiles of the governance distribution, they are also in the top rank of the stated variables.

A major advantage of the proposed set of indicators is that their assessment does not depend on the perception of participants and stakeholders (through surveys or interviews). In this study, public participation processes were used to validate the scores and not to generate them. Moreover, its biggest disadvantage or weakness occurs when evaluating the existence of elements associated with the governmental or managerial structure (e.g. number of commissions), because they do not take into account whether the commission operates well or not, only quantifies its existence. As a future line of work these elements must be refined.

These governance indicators could be very useful to compare the temporal evolution of the counties in the region after the proposed actions for the regional planning process or any other policy/administrative instrument are implemented. As the first managerial effort, the results established a good baseline in terms of governance for the full region, for each state and for all the littoral counties.

The study area comprises several of the poorest coastal states in Mexico, and the results obtained by means of the governance indicators verify the hypothesis that a relationships exist between poverty and low governance level. The significant correlation between poverty and governance level is a very interesting finding and could provide useful information to define governance and/or management interventions at the national, state or county level, starting with actions in the variables that define the most sensitive governance indicators to alleviate poverty. It is proposed as a future line of research further analysis of the relationships and interactions between poverty, governance and environmental quality.

As a managerial and decision-making tool, these indicators and indices may help to promote good practices because they are easy to monitor, transparent, are based on the best available scientific and public information, can be visualized in a GIS and are very useful to integrate not only the regional and marine use planning processes results, but also as a benchmarking strategy for every coastal county or state to attain coastal sustainability.

Appendix

Supporting Information associated with this article is available on-line at http://www.aprh.pt/rgci/pdf/rgci-578_Azuz-Adeath_Supporting-Information.pdf

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Analysis of the influence of ENSO phenomena on wave climate on the central coastal zone of Rio de Janeiro (Brazil)

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Abstract

This paper evaluates the influence of the El Niño – Southern Oscillation on the wave climate variability in the central region of Rio de Janeiro's coastal zone. The regional climate of the area was characterized using the WAVEWATCH III wave data model, obtained from NOAA, organized as a 35 year time series (1979-2013). These data were validated for the study area and a characterization and analysis performed by focusing on years with occurrence of strong El Niño/La Niña events. The correlation between the interannual variability of significant wave height and Oceanic Niño Index showed a slight reduction in significant wave height during El Niño years and the opposite pattern during La Niña years, with a lag of four months. This decrease could be attributed to the intensification of the South Atlantic High with a corresponding increase in the occurrence of subtropical jets during periods of El Niño. This weather change causes the blocking of cold fronts in the southern region of Brazil and the consequent reduction in the percentage of waves from the south along the southeast coast.

Keywords: climate variability, wave parameters, interannual time scale, seasonality, regional climatology

Resumo

Análise da influência de fenômenos ENOS no clima de ondas da porção central da zona costeira do Rio de Janeiro (Brasil)

Este artigo busca avaliar a influência do fenômeno El Niño - Oscilação Sul na variabilidade do clima de ondas da porção central da zona costeira do Rio de Janeiro. Para tanto, a climatologia regional da área foi caracterizada a partir de dados de ondas do modelo WAVEWATCH III disponibilizado pela NOAA, organizados numa série temporal de 35 anos (1979 - 2013). Esses dados foram validados para a área de estudo e, realizada sua caracterização e análise com enfoque em anos de acentuada ocorrência de eventos de El Niño/La Ninã. A correlação da variabilidade interanual da série de altura significativa de ondas e Índice de Niño Oceânico mostrou padrão de leve redução das alturas significativas em anos de El Niño e, o inverso para anos de La Niña, com defasagem temporal de quatro meses na região. Essa redução na altura significativa das ondas pode ser atribuída à intensificação da Alta Subtropical do Atlântico Sul e aumento na ocorrência de jatos subtropicais nos períodos de El Niño. Essa alteração no padrão meteorológico causa o bloqueio de frentes frias na região Sul do Brasil e consequente redução da porcentagem de ondas de sul na região sudeste.

Palavras-chave: variação climática, parâmetros de onda, escala interanual, sazonalidade, climatologia regional

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1. Introdução

The El Niño – Southern Oscillation (ENSO) is the dominant mode in ocean-atmosphere coupling variability on interannual time scales (Trenberth & Stepaniak, 2001). The El Niño is characterized as an abnormal warming in the sea surface that occurs during some years in the coastal zone of Peru and Colombia, changing the pattern of the climate systems on both local and regional levels (Trenberth, 1997). The La Niña is the opposite phase of the El Niño, characterized as an abnormal cooling in the surface water.

Although the El Niño is a regional phenomenon in the Pacific region, the climatic anomalies associated with ENSO are nearly global in extent and have a highly persistent nature (Kousky *et al.,* 1984). The ENSO atmospheric component, the "Southern Oscillation", corresponds to a zonal balance in the large scale air masses with a direct response in the variability of the atmospheric pressure (Aragão, 1998).

Knowledge of environmental conditions has fundamental importance for oceanic engineering (Souza & Ribeiro, 1988). As an example, beach morphology is dependent on the combined actions of local environmental conditions, sediment type and the previous wave behavior (Komar, 1976; Short, 1999; Muehe, 2011). Knowledge of the regional wave climate, in conjunction with that of morphological processes in the coastal zone, strengthens coastal management studies and the implementation of engineering structures at the coast (Pianca *et al.,* 2010).

Comprehending the relationship between ENSO events and changes in environmental parameters has numerous applications, such as the evaluation of the energetic potential of winds and waves in the coastal zone and in coastal management to support public policies. In a study of the energy potential of wind in the state of Ceará (Brazil), Araújo Júnior *et al.* (2014) verified that conditions to generate wind energy were better during the 1997-1998 El Niño period than during the La Niña event of 1998-1999, principally on the coast.

Impact studies of El Niño/La Niña events on regional climates can provide improvements to climate prediction techniques to support public policies. Changnon (1999) studied the impact of the 1997-1998 El Niño event on the economy and loss of life in the United States, using the state of California as an example. An analysis of ENSO predictions and ENSO's economic and social effects led the government of California to conduct impact reduction efforts, which decreased subsequent economic and human losses.

As yet, Brazil is still lagging studies that identify wave patterns during El Niño periods, and, as a consequence, also lacks the public policies regarding coastal management and coastal hazards that relate to those events. Accordingly, this work aims to characterize the regional wave climate of the central coastal zone of Rio de Janeiro through the analysis of a global wave model and the evaluation of apparent changes in the patterns of this data on an interannual time scale, focusing on several years during which El Niño and La Niña events occurred.

2. Methodology

2.1. Study area

The central area of the coastal zone of Rio de Janeiro used in this study is comprised of the waters from the continental slope to the coastal waters near the shoreline (Figure 1).

The wave climate for this region is that of predominantly "good weather" conditions with NE winds and a presence of storm waves mainly from the South Atlantic High (SAH) associated with frontal systems from the east-southeast (Silva et al., 2009).

Observations indicate that the mean wave height varies between 1.6 to 2.0 m during the "good weather" conditions. Waves with height greater than 3.0 m frequently come from the S and SW quadrants (Bastos & Silva, 2000). Waves from the NE and E are low energy but the most frequent, based on a comparison of the wave energy distribution by incidence direction (Muehe & Corrêa, 1989). According to Diretoria de Hidrografia e Navegação (DHN/Navy of Brazil), the tidal variation ranges from 1.3 m at spring tides to 0.3 m at neap tides.

2.2. Data set

To determine the wave climate during El Niño/La Niña event along the Rio de Janeiro coast, simulation data was obtained from the WAVEWATCH III wave model, available from the National Oceanic and Atmospheric Administration (NOAA), with a global spatial resolution of 0.5º and 3 h temporal resolution (NOAA WAVEWATCH III - NWW3).

Two versions of the model dataset were used. The first was a reanalysis of historical waves hindcast using WAVEWATCH III, version 2.22 (Tolman, 2002) for the period from January 2010 to December 2013. The second was a reanalysis of waves hindcast using WAVEWATCH III, version 3.14 (Tolman, 2009) with input data from the Climate Forecast System Reanalysis Reforecast (CFSRR) wind reanalysis (Spindler *et al.,* 2011), obtained from the National Center for Environmental Prediction (NCEP) from January 1979 to December 2009 (Chawla *et al.,* 2012, 2011).

From this data, the variables used were significant wave height, peak period and peak direction (ranging from 0 to 360º, where 0 represents waves from the north) which were extracted for the total period from January 1979 to December 2013 (35 years). To represent the

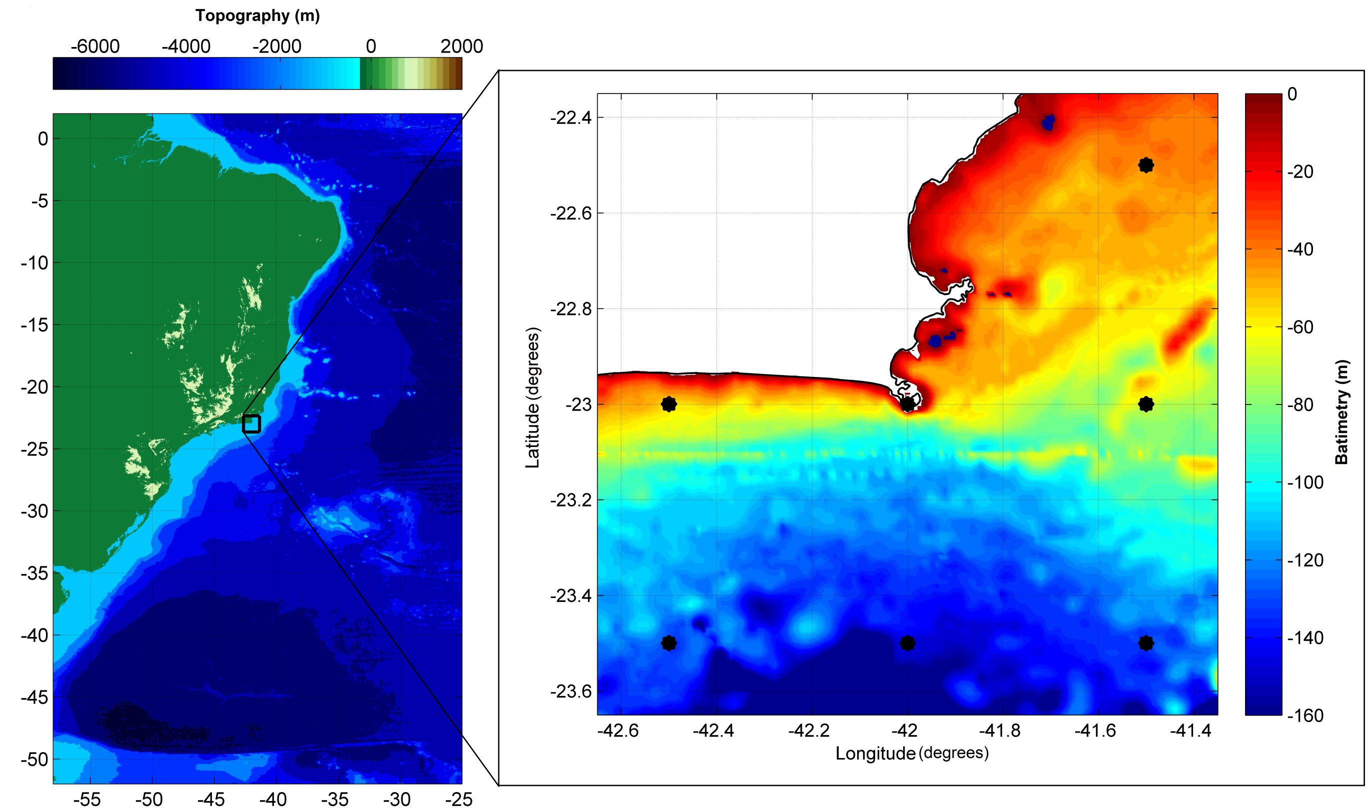

Figure 1 - Study area used in the wave climate analysis, shown using bathymetry from TOPEX/POSEIDON (Becker *et al.* 2009) near Cabo Frio, on coastal region of Rio de Janeiro, Brazil. The black dots represent the spatial resolution of NOAA WAVEWATCH III model data.

Figura 1 - Área de estudo utilizada na análise do clima de ondas, demonstrada por batimetria TOPEX/POSEIDON (Becker et al. 2009) próximo a Cabo Frio, na região costeira do Rio de Janeiro, Brasil. Os pontos em preto representam a resolução espacial dos dados do modelo NOAA WAVEWATCH III.

central coastal region of Rio de Janeiro, near the city of Cabo Frio, the area was defined as between 22.5 - 23.5º S and 42.5 - 41.5º W (Figure 1).

The Oceanic Niño Index (ONI) series used are available from NOAA's Climate Prediction Center (Figure 2). This index was calculated as a 3 month moving average of the temperature anomaly over the period under analysis using the Extended Reconstructed Sea Surface Temperature - ERSST.v3b dataset (Smith *et al.*, 2008) for the Niño 3.4 region (5º N – 5º S, 120º W – 170º W). According to Larkin & Harrison (2005), NOAA defines El Niño events as periods of three consecutive months with an ONI that exceeds 0.5ºC, while La Niña events are identified for an ONI below -0.5ºC.

From this index, we selected the years 1997 and 1998, which represented the beginning and the end, respectively, of the strongest El Niño period of the 20th Century (Wolter & Timlin, 1998). We also selected the year 2000, a representative year within a long period of La Niña (from 1998 to 2001) that occurred after the 1997-1998 El Niño, classified as a moderate to intense event (Shabbar & Yu, 2009). For a more significant representation of the mean pattern in El Niño/La Niña years, the years with major temporal persistence of the phenomena were chosen (1983, 1987, 1992, 1997 and 2003 for El Niño years and 1988, 2000 and 2008 for La Niña years).

For the correct application of the model's data, adequate validation is necessary. Data validation of NWW3 was performed using a statistical comparison to data from a stationary meteo-oceanographic buoy using a period from July 17 to December 31, 2013. This buoy from the Instituto de Estudos do Mar Almirante Paulo Moreira (IEAPM/Navy of Brazil) is part of the SIODOC project (Sistema Integrado de Obtenção de Dados Oceanográficos) and is located at 22º 59.62' S – 42º 11.65' W. The resolution of the data was in 1 hour time intervals and is available at http://metocean.fugrogeos.com/marinha/ .

2.3. Statistical treatment and model validation

For many applications, a time series can be considered as a linear combination of periodic or quasi-periodic components (with fixed amplitudes and phases) on which a tendency and high frequency noise are superposed (Emery & Thomson, 2001). Fourier analysis

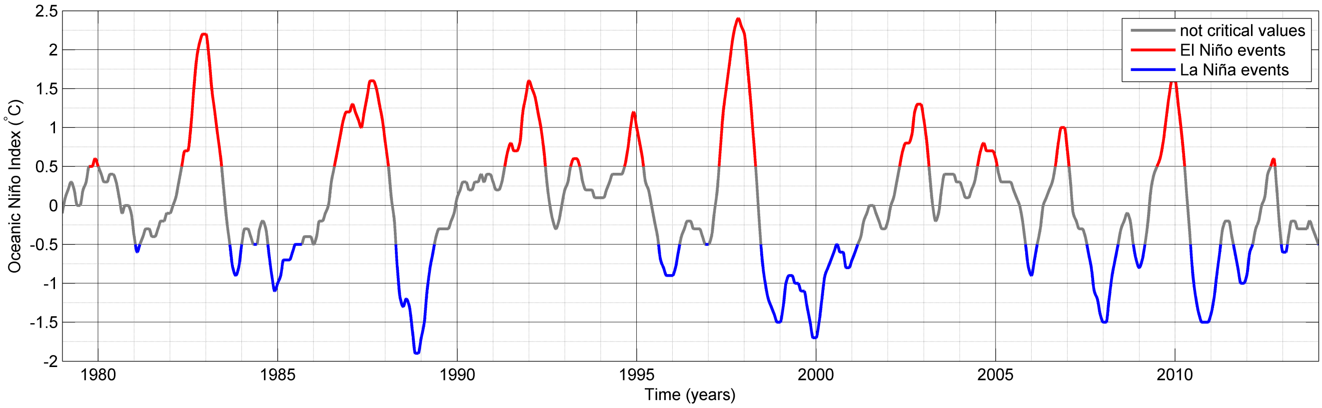

Figure 2 - Temporal variability of the Oceanic Niño Index for the period from Jan 1979 to Dec 2013, with the occurrences of El Niño periods presented in red and La Niña events in blue. This monthly index considers the 3 month averages of the ERSST.v3b sea surface temperature anomaly Data source: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ ensoyears.shtml.

Figura 2 - Variabilidade temporal do Índice de Niño Oceânico para o período de Janeiro de 1979 a Dezembro de 2013, com a ocorrência de períodos de El Niño representados em vermelho e, os eventos de La Niña em azul. Esse índice mensal considera a média de 3 meses da anomalia de temperatura do mar em superfície do ERSST.v3b Fonte dos dados http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml.

thereby considers as a basic premise that the time series can be reproduced as a sum of wave signals (sines and cosines) with the mean value of the series. The time series was decomposed to observe the individual signature of each wave signal. To calculate the significance of the power spectrum's peaks, the red noise was computed based on a first order autoregression process (Zhang & Moore, 2011). Peaks in the time series' power spectrum that are above the red noise's Fourier spectrum have a 95% confidence level.

For the statistical analysis, the time scale of the buoy data was reduced to obtain 3 hour means. A spectral filter was used to identify and remove high frequency signals. The high frequency noise can be related to a series of factors, such as characteristics of the equipment used. The significant wave height and peak period were chosen for analysis from the buoy data because the peak direction data was not available for the buoy dataset. The NWW3 model data used to compare with the buoy data uses the point 23º S – 42º W, which was the closest to the point where the buoy was anchored.

The mean and standard deviation were calculated for each variable over the analysis period. The correlation coefficient is used to determine how well two (or more) variables co-vary in time (or space) (Emery & Thomson, 2001). Considering two distinct series varying in time, the linear correlation coefficient can be calculated considering its displacement in time, referred to as cross correlation.

This coefficient suggests the linear dependency of the compared data because the values indicate their degree of dispersion around the adjustment function (linear regression). It functions as a quantifier of the intensity and direction of this linear relationship (Chen *et al.*, 2013). The values of this parameter oscillate between 1 and -1, where values near zero indicate that the variables are not related. High positive values indicate that the variables exhibit similar behavior, while high negative values indicate an inverse relationship in the behavior of the variables.

Considering an analysis focused on interannual variability, a statistical treatment was applied to the time series of the wave parameters to remove the seasonal signature and calculate cross correlations between the wave parameters and the ONI. The "climatology" method was used, which consisted of subtracting the monthly climatology from the 35 years of the series that had previously been reduced to monthly time steps. A 3 months running mean was then applied. This is the same methodology used to obtain the ONI data (Douglass, 2011). The objective of this filtering was to remove characteristic oscillations due to seasonality and other events with high frequency such as frontal system passages.

Verification that both variables are related can be obtained from the empirical evidence that there is a correspondence in the patterns of those variables higher than expected than if using random data (Orcutt & James, 1948). To test the significance of the correlations between wave parameters and the ONI, random series were generated from each of the original series. These were correlated, forming a population of correlations comprising a total of 10,000 samples.

The probability of a random variable showing a determined value is represented by the Cumulative Distribution Function (CDF). A non-parametric estimate was used to adjust the CDF by determining an empirical (ECDF), thus without use of a theoretical model with a specific distribution.

In this study, the Kaplan-Meier estimator was used to estimate the CDF (Kaplan & Meier, 1958; Lawless, 2002) as an empirical function, considering a test for full population (N = 10,000) and another for a subset of that population (N = 200). For comparison with the empirical method, an adjustment of the theoretical CDF of the resultant population distribution using a normal function (Gaussian) was selected.

For the validation of NWW3 data with the buoy data and the comparison between theoretical and empirical CDFs, the mean absolute error (MAE) and relative (RMAE) were also calculated. The RMAE is the MAE normalized using the average values of the buoy data to obtain the proportion of the model error to the mean value observed in nature. The MAE is one of the best parameter choices to quantify the average error, using the magnitude of the absolute difference between the modeled and observed data at each point of time series (Willmott, 1982; Willmott & Matsuura, 2005). For this parameter, zero represents the perfect adjustment between modeled and observed data.

As part of the NWW3 validation, a parameter proposed by Willmott (1981) was also calculated. A parameter value of 1 is a perfect fit between the results obtained by the model and those observed, while 0 represents a complete mismatch. Although the correlation indicates the interdependence of the series (the degree of dispersion of the series considering a linear adjustment), the Willmott parameter is indicative of the similarity in the compared data, related to the remoteness of the estimated values observed in both series (Chen *et al.*, 2013).

3. Results and discussion

3.1. NWW3 data validation

The following image (Figure 3) shows the significant wave height and peak period data of NWW3 contrasted with buoy data acquired near Arraial do Cabo, before and after receiving spectral treatment. If the high frequency spectrum was removed from the data, it did not change the overall behavior of the curve, but did eliminate the high frequency noise in the original data. Thus, there is a reduction of the standard deviation of the filtered data values from the original, and a slight attenuation of extreme events.

It is remarkable that the modeled data show an overall behavior similar to data found in the environment. The linear correlation index calculated for the buoy data after spectral filtering was approximately 0.80 for the

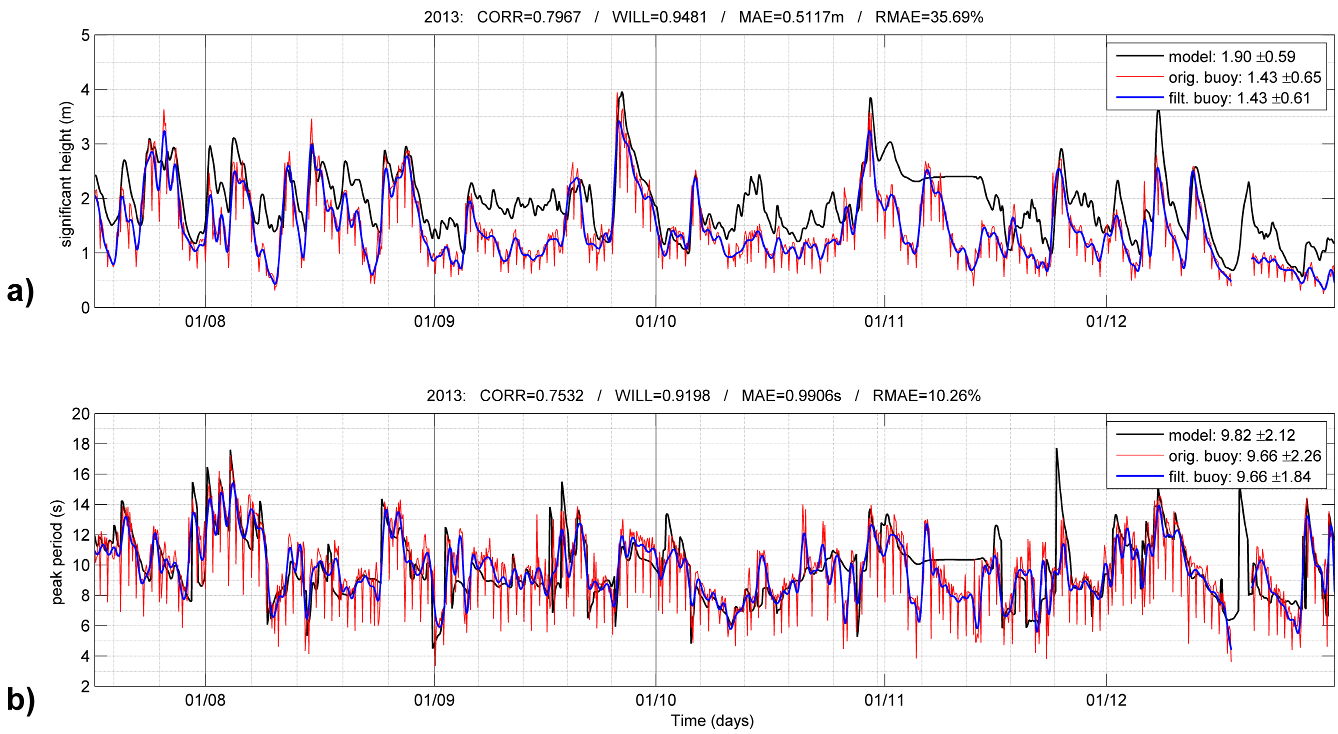

Figure 3 - Comparison between the original wave data from the buoy, where can be observed the same data before and after filtering and, the NWW3 data. The statistical parameters referring to the comparison between buoy data after filtering and NWW3 data are presented for: (a) significant wave height and; (b) peak period.

Figura 3 - Comparação entre os dados de onda originais provenientes da boia, onde podem-se observar os mesmos dados antes e depois da filtragem e, o dado do NWW3. Os parâmetros estatísticos referentes à comparação entre os dados de boia após filtragem e os dados o NWW3 são apresentados para: (a) altura significativa da onda e; (b) período de pico.

significant wave height and 0.75 for the peak period. The Willmott parameter values were 0.95 for significant wave height and 0.92 for the peak period.

In this context, no reference values have been established for the Wilmott parameter, but it is generally accepted that values around 0.5 indicate that the model reproduces about half of the observed variance (Hetland & Dimarco, 2012). Chen *et al.* (2013) consider an indication of good accuracy to be correlation values greater than 0.77 and the Willmott parameter above 0.70. The high values for both parameters indicate that in addition to showing a similar oscillation pattern, the data sets show a strong fit, which demonstrates that the difference between each pair of points for this series is similar for the entire set of series.

On first examination, observing the average values of the series for both the model and buoy data, a notable overestimation by the model is evident. The mean modeled significant wave height is approximately 0.47 m higher in comparison to the values given by the buoy. The same occurs for peak period, but with a smaller difference, with an average of 0.16 s greater for the model than for the buoy. For either the significant wave height or the peak period, the differences between the sampled and modeled mean values lie within the standard deviation range.

The average error, which quantifies the mean difference between the model values in comparison to the observed data from the buoy, was approximately 0.51 m for significant wave height (35.69% error), while for the peak period this value was 0.99 s (10.26% error). A comparison between observed data and NWW3 near the Florianópolis region by Pianca *et al.* (2010) confirms the similarity between model and environment, showing the same pattern of model's overestimation for the significant wave height data.

Hanson *et al.* (2009) reviewing NWW3 performance in the Pacific Ocean also found a remarkable correlation with observational data, greater than 0.78 for wave height and 0.88 for the period. That study found a maximum error of 0.5 m in wave height that is associated with the use of the hindcast altimetry data, which tends to overestimate wave height values. Rogers et al. (2012) found a 10% overestimation in the referred data.

For both variables in the NWW3 data we can observe that the first two weeks of November presented a constant value, differently of the buoy data. This can represent many types of errors, probably related to the data assimilated by the model in the reanalysis process. The period occurs after high values of significant wave height and peak period, which can suggest the approximation of a cold front passage in the study area both in the beginning and the middle of the period. These consecutive passages of cold fronts can promote cloud cover persistence, which prevents data collection via remote sensing.

The validation authenticates the use of these data for environmental studies. However, although validated for the North and Tropical Atlantic, models on a global scale such as this need further comparison with data collected in the vicinity of the south and southeast Brazilian Continental Shelf. Data sets such as NWW3 formerly had a significant discrepancy in the Southern Hemisphere, particularly as a consequence of few measurements in situ in these regions (Caires *et al.,* 2004). This type of validation would improve models with global resolution in the South Atlantic region.

3.2. Wave climate characterization

Starting from the analysis of time series for wave parameters in the region (see *Supporting Information I*), it can be seen that the significant wave height for the study area has an average of approximately 1.80 ± 0.51 m, with marked seasonality that results in an average oscillation limited by the standard deviation. This same seasonal pattern is observed for both the peak direction ($147.42 \pm 43.52^{\circ}$) and peak period (9.80 ± 2.25 s).

In this context, the months of May and September exhibited a pattern of higher significant heights predominantly from the South quadrant, with long periods (around 13 s). In contrast, the austral summer is characterized by lower significant wave heights predominantly from the East with shorter periods (around 7.5 s). Figures 4a, 4b and 4c show that significant wave height varies between 1 and 4 m for the majority of the values, with the highest concentration of values around the average. The peak period shows the same pattern, with samples concentrated between 5 and 15 s and a predominance of samples around the average value. The peak direction ranges from 50° to 220° and presents a bimodal pattern, with one mode centered at 90° and another around 180°.

The monthly climatology of wave parameters (Figures 4d, 4e and 4f) show that the maximum average values for significant wave height occur at the end of the austral winter (with average values of approximately 2.0 m) and the minimum in late summer (with average values of 1.6 m). Unlike significant wave height, the direction and peak period have maximum average values in late autumn (with average values around 10.5 s - SSE) and their minimum in the middle of summer (with average values around 8.5 S-SE). The maximum values for these variables preceded the maximum values of significant wave height.

Surface gravity waves can be categorized into two types. The first type, "wind sea" waves, have periods of less than 10 s with an irregular appearance and short

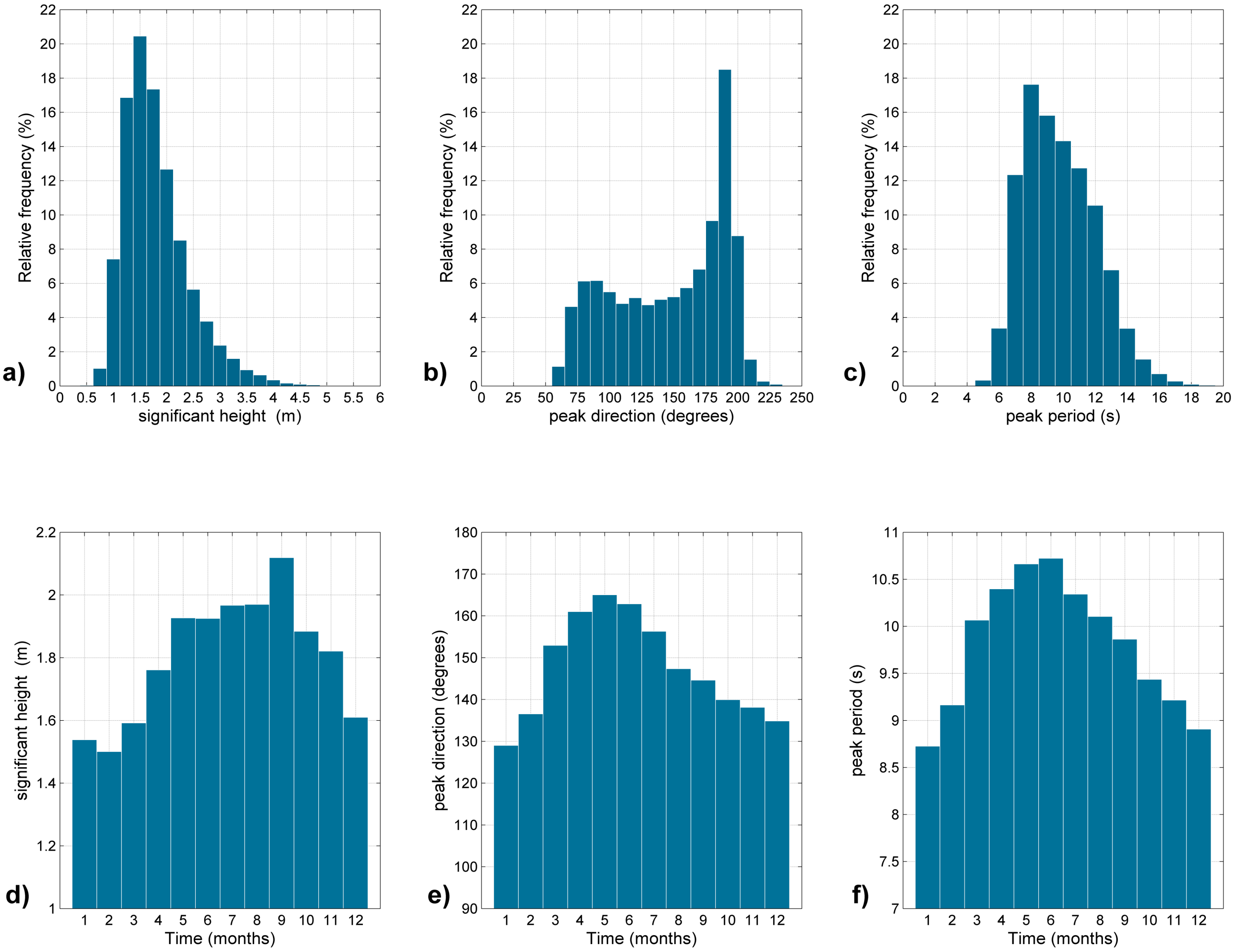

Figure 4 - Histogram referencing the time series data of significant wave height (a), peak direction (b) and peak period (c) for the period from Jan 1979 to Dec 2013 and considering a sample size of 102,272 points. The monthly climatology for the same period is shown for the same parameters in (d), (e) and (f), respectively.

Figura 4 - Histograma referente aos dados de série temporal de altura significativa da onda (a), direção de pico (b) e período de pico (c) para o período de Janeiro de 1979 a Dezembro de 2013 e, considerando um tamanho amostral de 102272 pontos. A climatologia mensal para o mesmo período é apresentada para os mesmos parâmetros em (d), (e) e (f), respectivamente.

wave lengths, and are generated by local winds. The second type are "swell" waves, which have periods between 10 and 20 s, characteristic long wave lengths and an almost sinusoidal form, present far from their generation area (Holthuijsen, 2007; Laing, 1998).

The wave regime in this region is controlled by the South Atlantic High and the passage of cold fronts (Pianca *et al.,* 2010). Thus, with respect to the region under consideration, the first mode (NE-SE) is characterized as waves associated with the South Atlantic Anticyclone as a result of the downward arm of the Hadley cell (Campos, 2009) which promotes moderate winds. The associated "good weather" waves have a low peak period (up to 7.5 s). The second mode (S-SW) is associated with the migration of polar air masses forming cold fronts in the region; these waves present peak periods between 11 and 15 s and carry more energy, noted by Muehe & Corrêa (1989), Pianca *et al.* (2010) and Souza & Ribeiro (1988).

The directional histograms for significant wave height and peak period (Figure 5) distinctly show the same general pattern. The highest concentration of waves is from the quadrant between the NE and SW. The highest significant wave height values are concentrated between the SE and SW, with predominant periods longer than 10 s. The waves with shortest periods (less than 10 s) originated from the direction between NE and SE were the minor percentage of the total These two patterns of waves represent the two distinct types of wave characterized by Souza & Ribeiro (1988). As seen in these data, Bastos & Silva (2000) similarly observed that for the region, the occurrence of waves higher than 3.0 m most often originates in the S and SW.

Figure 6 shows climatological directional histograms observed for the four seasons of the year, in which all seasons maintain the mean pattern of having greater significant wave heights and peak periods from the S. In the austral summer, the waves appear to be distrib-

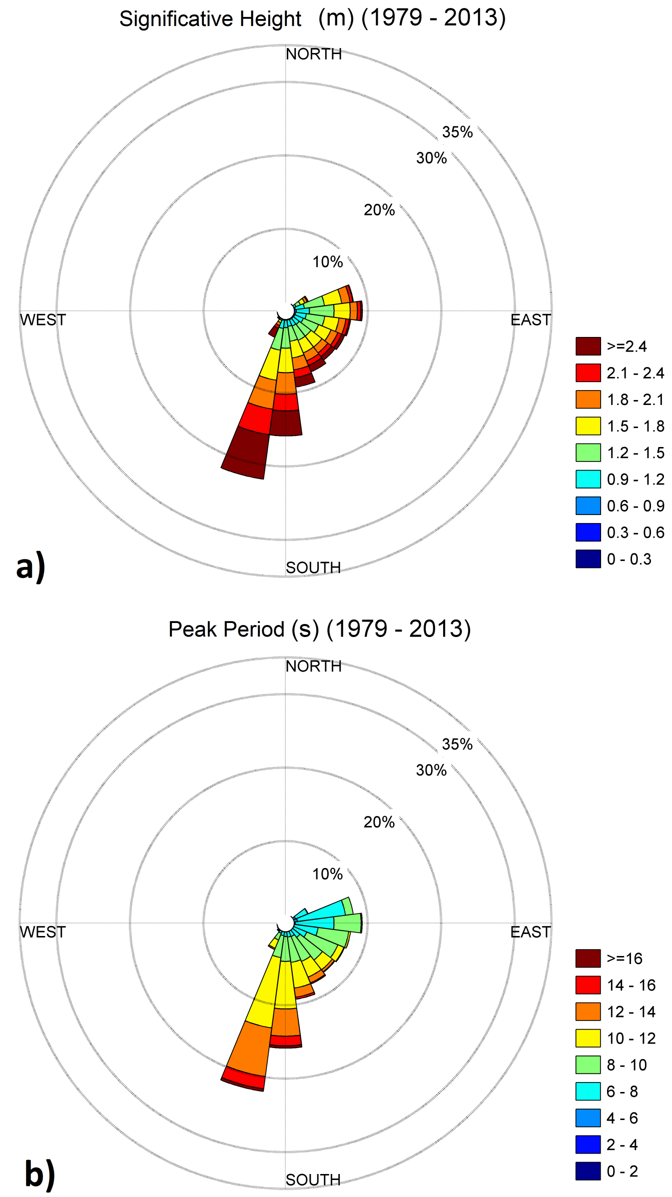

Figure 5 - Directional histograms of wave climatology for the period from Jan 1979 to Dec 2013 in 15° intervals, showing: (a) the significant wave height and; (b) the respective peak period.

Figura 5 - Histogramas direcionais da climatologia de ondas para o período de Janeiro de 1979 a Dezembro de 2013, em intervalos de 15o, mostrando em: (a) altura significativa de onda e; (b) respectivo período de pico.

uted in a uniform pattern from the E to S quadrants, while in autumn, a higher concentration of wave samples originates from the S and SW, presenting a nearly unimodal pattern. This pattern is repeated in the winter with a greater occurrence of waves from the E. It returns to a more homogeneous pattern in the spring, however, with a larger signature of S-SW waves and higher rates of waves with over 1.8 m heights. This pattern is similar to that verified by Pianca *et al.* (2010) for the Brazilian southeast region.

Concurring with our findings, in a wave climatology study from 1991 to 1995, Vale (2012) observed that the greatest percentage of extreme events of NE waves in the Campos Basin region occurred during the austral summer and had a lower incidence in the fall.

3.3. Interannual variability and El Niño interference in regional climatology

We can observe in Figure 7, that the periods of 1 and 1.5 years are detached in the Fourier's spectrum from the time series of the three wave parameters under analysis, as discussed previously. The seasonality and other signals with high frequencies observed in this time series masked the observation of interannual variability.

We show, in Figure 8, the frequency spectrum related to the ONI for the period 1979 to 2013 with the same wave data after statistical treatment to remove seasonality. The highest spectral power values refer to frequencies lower than 1 cycle by year (c.b.y). It is remarkable that after statistical treatment to remove seasonality, the wave data showed greater emphasis on low frequency signals without significantly changing the default signature. However, the high frequencies were still very prominent. This noise should have a negative influence on the correlations between these data and the ONI.

Comparing the ONI and the significant wave height after removal of seasonality no clear correlation is apparent between all the datasets for the three parameters, which is confirmed by the low linear correlation values shown (see *Supporting Information II*). However, according to Trenberth & Stepaniak (2001), the definition of El Niño indices (which use anomaly temperatures in the Pacific to identify the El Niño and La Niña periods) do not permit the discrimination of the characteristics of its effects in other regions; this causes difficulty in mapping a relationship between this index and the variability of some parameters on the Brazilian coast.

Examining cross-correlations between series for parameters concerning the wave and the ONI (Figure 9), the highest correlation coefficient was observed for the significant wave height parameter, approximately -0.19, with a time delay of four months. This delay suggests that the most likely correlation occurs with a 4-month response lag. The peak direction showed a negative correlation of approximately -0.14, with a lag of 8 months. The peak period, however, showed a positive correlation of 0.11 with zero lag. These correlation values, although apparently small, are above the minimum level of significance, even when using tests with a reduced N sample size (Figure 10). We need to consider the signature of the high frequency in wave parameters' data, which can reduce comparison of these two datasets.

This data indicates that in El Niño years (positive ONI), there would be a slight reduction in significant wave heights in the coastal region of Rio de Janeiro, with a

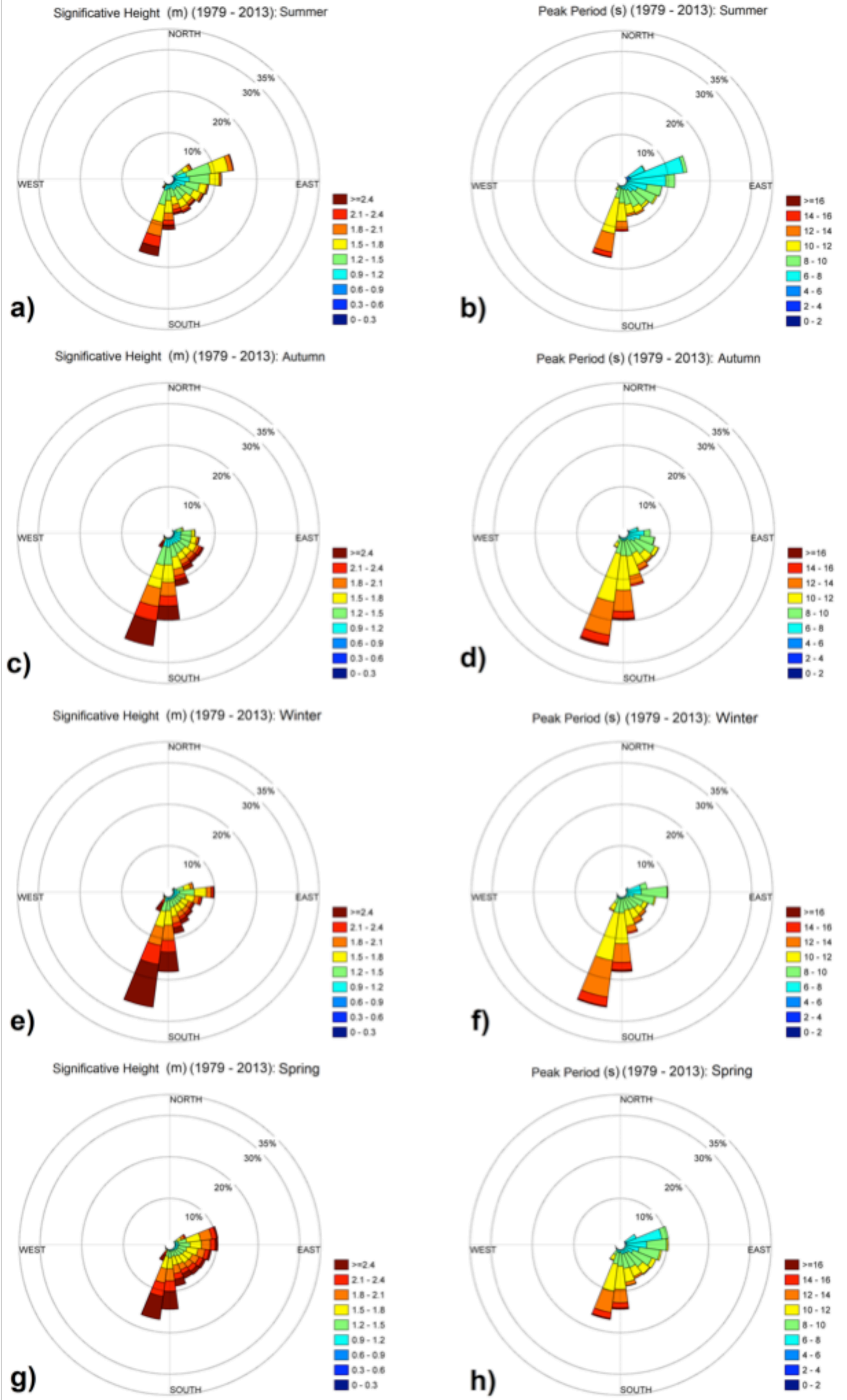

Figure 6 - Directional histograms of wave climatology for the period from Jan 1979 to Dec 2013, in 15° intervals. The significant wave height and peak periods, respectively, are presented for austral seasons of : (a) and (b) - summer (DJF); (c) and (d) - autumn (MAM); (e) and (f) - winter (JJA) and ; (g) and (h) - spring (SON).

Figura 6 - Histogramas direcionais da climatologia de ondas para o período de Janeiro de 1979 a Dezembro de 2013, em intervalos de 15º. A altura significativa das ondas e períodos de pico, respectivamente, são apresentados para as estações do ano no hemisfério sul: (a) e (b) – verão (DJF); (c) e (d) – outono (MAM); (e) e (f) – inverno (JJA) e; (g) e (h) – primavera (SON).

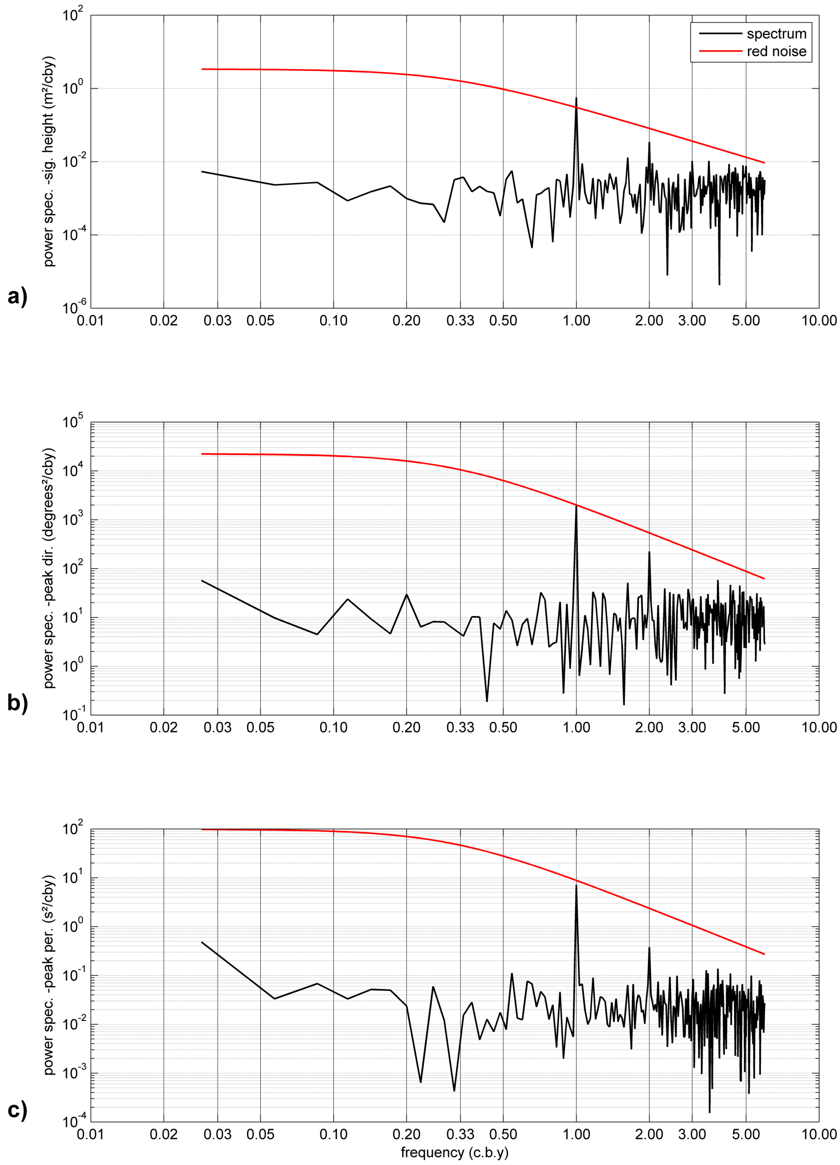

Figure 7 - Frequency Spectrum referring to the significant wave height (a), peak direction (b) and peak period data (c) for the period from Jan 1979 to Dec 2013. The red noise spectrum represents a 95% confidence level and the units of frequency are presented in cycles by year (c.b.y.).

Figura 7 - Espectro de frequências referente aos dados de altura de onda significativa (a), direção de pico (b) e período de pico (c) para o período de Janeiro de 1979 a Dezembro de 2013. O espectro do "ruído vermelho" representa num nível de confiança de 95% e, as unidades de frequência são apresentadas em ciclos por ano (c.b.y. – sigla em inglês).

delay of 4 months from the peak of the El Niño in Pacific waters. A study by Enfield & Mayer (1997) showed a correlation of -0.3 with a gap of 4 months between the temperature anomalies in the surface sea water in the South Atlantic and the Pacific surface temperature index, an index similar to the NINO3 index that is often used in studies of ENSO cycles (Enfield & Mayer, 1997). In the same study, the wind data preceded the response by two months, the time expected for variations in atmospheric patterns to be reflected in the surface of the sea.

After presuming that there was no strong correlation between the ONI and the other wave parameters, we chose to observe the wave pattern for each season of the year according to the index shown in Figure 2, considering years with significant El Niño and La Niña events. These data were compared for a more detailed observation of differences during ENSO periods using the climate pattern shown in the 31 year series of wave behavior data and focusing on the differences in the seasonality of these parameters.

The beginning of an El Niño period, 1997, was examined to compare its wave pattern (see *Supporting Information III*) to the wave climatology (Figure 6). In the summer, a smaller percentage of incident waves with more than 1.8 m in height were observed, along with a

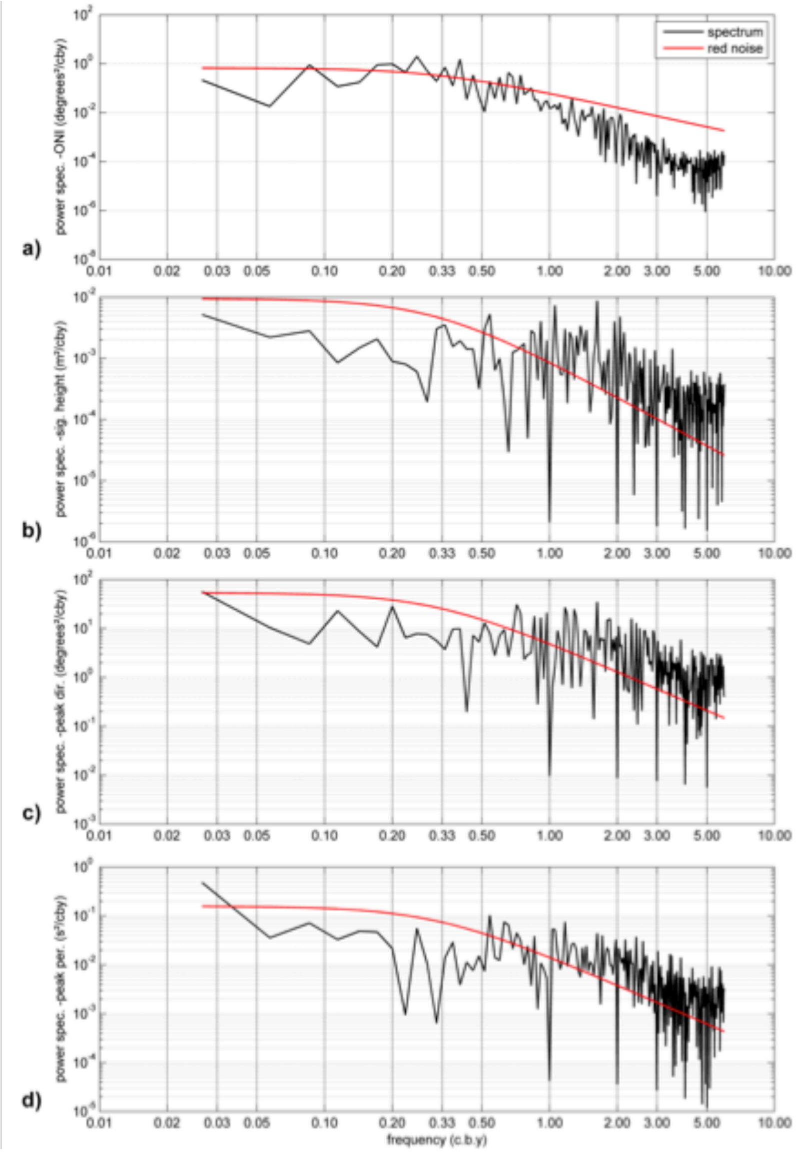

Figure 8 - Frequency Spectrum referring to the Oceanic Niño Index (a) and the wave parameters after removing seasonality for the period from Jan 1979 to Dec 2013, being: (b) significant wave height; (c) peak direction and; (d) peak period data. The red nose spectrum represents a 95% confidence level and the units of frequency are presented in cycles by year (c.b.y.).

Figura 8 - Espectro de frequências referente aos dados de Índice de Niño Oceânico (a) e os parâmetros de onda após remoção da sazonalidade para o período de Janeiro de 1979 a Dezembro de 2013, sendo: (b) onda significativa; (c) direção de pico e; (d) período de pico. O espectro do "ruído vermelho" representa num nível de confiança de 95% e, as unidades de frequência são apresentadas em ciclos por ano (c.b.y. – sigla em inglês).

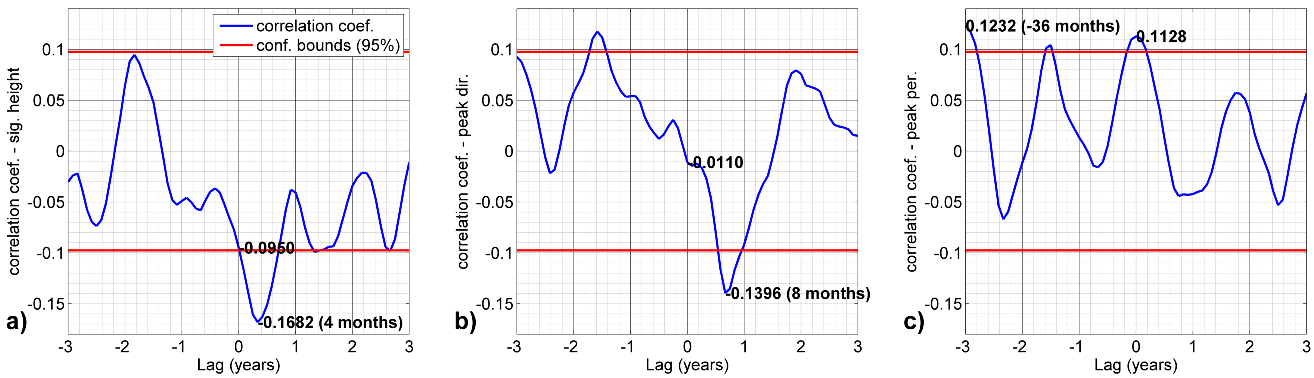

Figure 9 - Cross-correlation between the Oceanic Niño Index and time series for: (a) significant wave height; (b) peak direction; (c) peak period.

Figura 9 - Correlação cruzada entre o Índice de Niño Oceânico e as series temporais para: (a) altura significativa de onda; (b) direção de pico e; (c) período de pico.

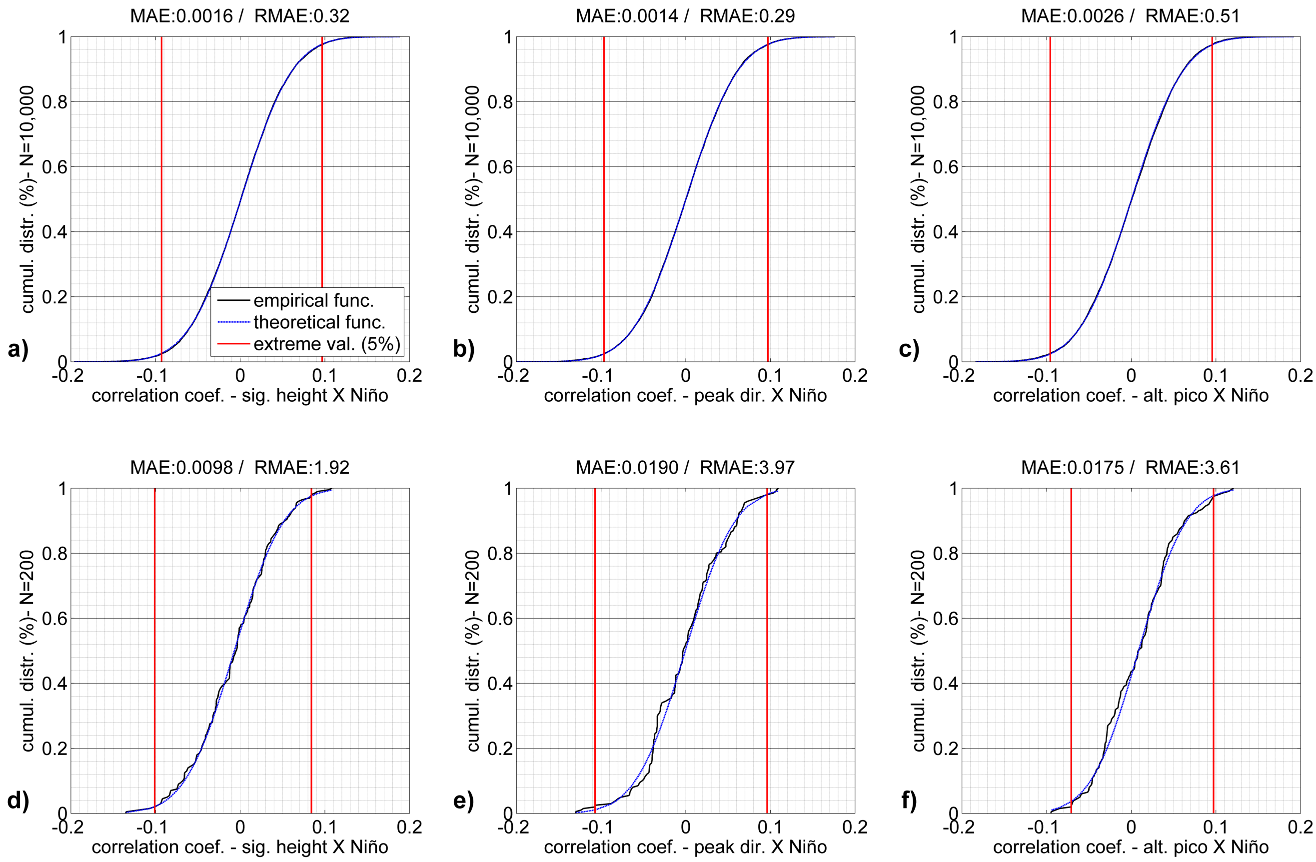

Figure 10 - Comparison of theoretical and empirical Cumulative Distribution Functions (CDF and ECDF) to a sample population of correlations between Oceanic Niño Index and time series of wave parameters, considering tests with N = 1,000 (a), (b) and (c) and N = 200 (d), (e) and (f).

Figura 10 - Comparação entre as Funções de Distribuição Cumulativa teóricas (CDF – sigla em inglês) e empíricas (ECDF) para uma população amostral de correlações entre o Índice de Niño Oceânico e as séries temporais para os parâmetros de onda, considerando teste com N = 1000 (a), (b) e (c), e N = 200 (d), (e) e (f).

higher concentration of waves from the E-NE. In autumn, the pattern remained similar to the general climatology, while in winter a clear reduction in the percentage of waves from S-SW was noted. These waves returned to intensify in the spring, exceeding the percentages present in the general climatology for the period 1979-2013.

For the El Niño year 1998 (see *Supporting Information IV*), which comprises the end of the same El Niño event referenced above, the wave pattern showed a similar pattern to that of 1997 throughout the year, except during winter and spring. The winter period showed a high incidence of waves from the E with low values for the significant wave height and peak period, while a higher occurrence of waves from the SE was observed in the spring.

For the La Niña year 2000 (see *Supporting Information V*), a higher percentage of E-NE waves was observed in summer if compared to the general climatology, as was observed in El Niño events. A reduction in the occurrence of S-SW waves was observed during the autumn and an increase in winter. During the spring, an increase in the percentage of E-NE waves was noted.

Thus, in general, the reduction of the average of significant wave height in El Niño years shown in the cross-correlation data is seen most clearly with respect to reducing the percentage of incident waves from the SSE-SSW during the winter period in those years. The reverse is true in La Niña years. Also observed in El Niño events is an increase in the percentage of waves coming from ENE in summer and autumn, while in the spring season, La Niña corresponds with an increase of ENE-ESE waves and decrease in SSE-SSW related to the El Niño.

Examining the mean pattern of the years' compositions with the occurrence of the most persistent El Niño and La Niña events (Figures 11 and 12, respectively), we observed a general pattern very similar to that observed in the seasonal climatology of the 35 years (Figure 6) for all seasons. It is evident, however, that a slight decrease in SSE-SSW wave percentages occurs during the winter in El Niño years, while La Niña years have slight

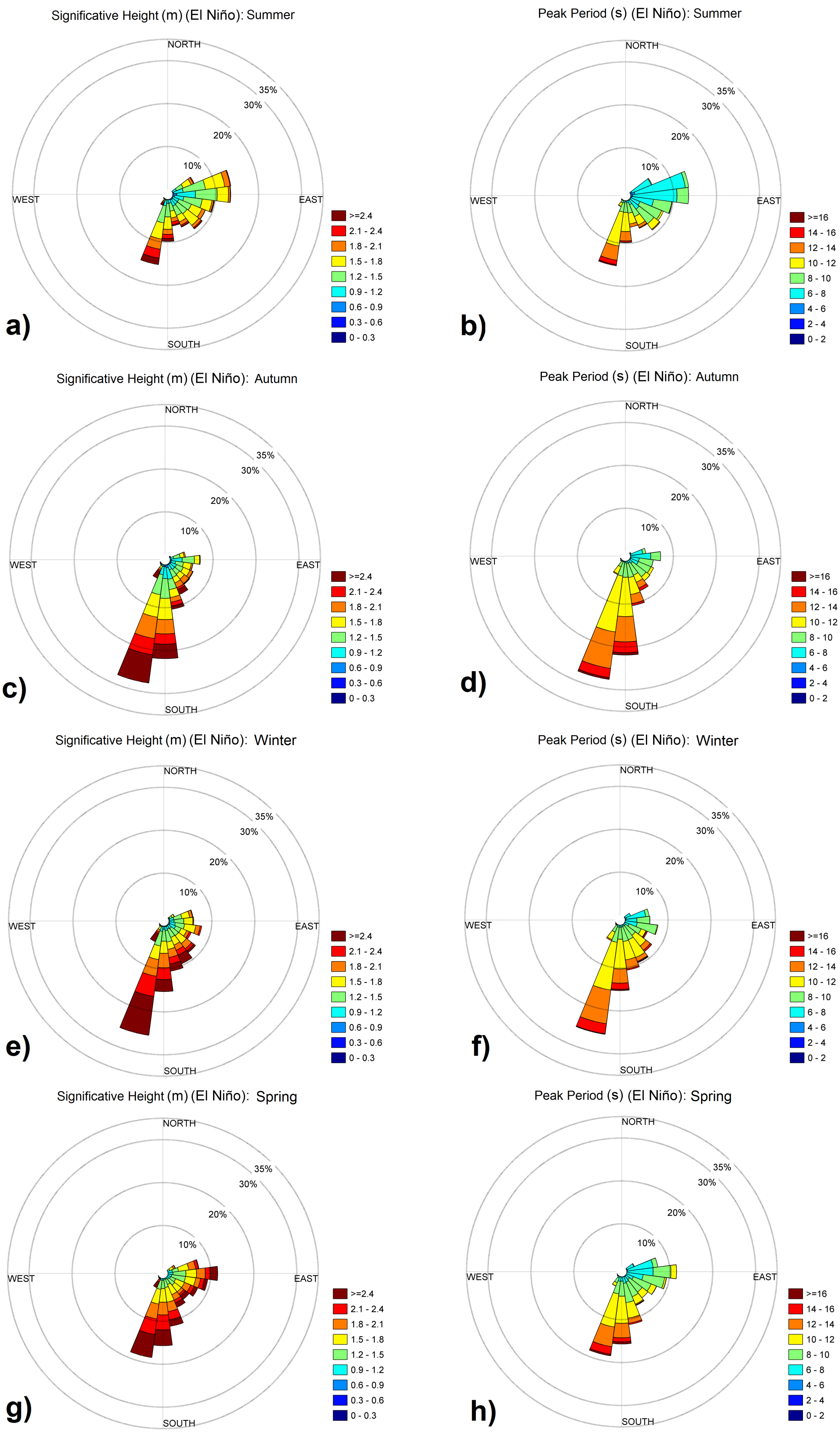

Figure 11 - Directional histogram for wave data for the most persistent El Niño years (1983, 1987, 1992, 1997 and 2003) presented with significant wave height and its period, respectively, for Austral seasons: (a) and (b) - summer (DJF); (c) and (d) - autumn (MAM); (e) and (f) - winter (JJA); and (g) and (h) - spring (SON).

Figura 11 - Histogramas direcionais dos dados de onda para o os anos de El Niño mais persistente (1983, 1987, 1992, 1997 e 2003) apresentando a altura significativa de onda e seu período de pico, respectivamente, para as estações do ano no hemisfério sul: (a) e (b) – verão (DJF); (c) e (d) – outono (MAM); (e) e (f) – inverno (JJA) e; (g) e (h) – primavera (SON).

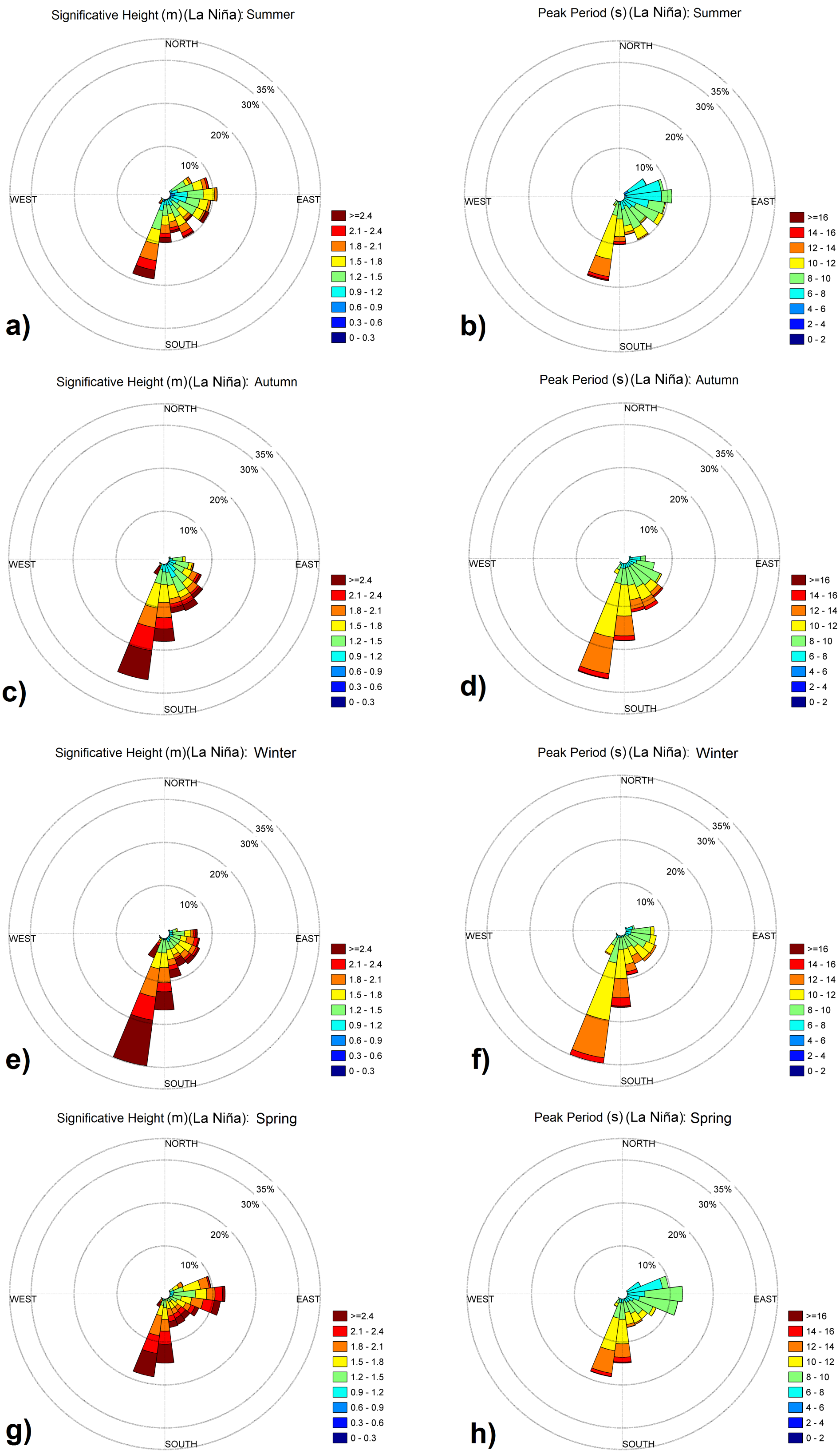

Figure 12 - Directional histogram for wave data for the most persistent La Niña years (1988, 2000 and 2008) presented with significant wave height and its period, respectively, for Austral seasons: (a) and (b) - summer (DJF); (c) and (d) - autumn (MAM); (e) and (f) - winter (JJA); and (g) and (h) - spring (SON).

Figura 12 - Histogramas direcionais dos dados de onda para o os anos de La Niña mais persistente (1988, 2000 e 2008) apresentando a altura significativa de onda e seu período de pico, respectivamente, para as estações do ano no hemisfério sul: (a) e (b) – verão (DJF); (c) e (d) – outono (MAM); (e) e (f) – inverno (JJA) e; (g) e (h) – primavera (SON).

increase in wave percentages from the same direction, for the same season. This fact corroborates the observations in the analysis of specific El Niño years/La Niña events, but also shows that these events exhibit different characteristics through the seasons in different years.

Low correlation values are justified by the small variation in the wave percentages, concentrated in a specific season. However, the persistence of this characteristic in various events of El Niño/La Niña needs to be emphasized.

In general, the literature shows that in El Niño events there is a weakening of the ascending branch of the Hadley cell over the tropics in South America and the Intertropical Convergence Zone (ITCZ) is inhibited; the opposite occurs in La Niña events: an intensification occurs in ascending and descending branches associated with Walker and Hadley cells (Souza & Ambrizzi, 2002). Kousky *et al.* (1984) observe that the strengthening of the Hadley cell favors the intensification of the trade winds, reflecting a higher transfer of energy to the E waves in the study area for periods of El Niño, reversing this process in periods of La Niña. In seasonal climatologies (Figures 6, 11 and 12), it can be seen, discreetly, that a higher percentage of waves from NE-SE quadrant occurs in the years of El Niño events.

In El Niño events, there is a reduction in air pressure over the Pacific, increasing upward movements in the region, changing the zonal circulation (Walker cell), which increases the downward movements in tropical regions such as the Brazilian Northeast. In the state of Ceará, for example, an intensification of the winds on the surface is observed in El Niño periods and a weakening of the winds in the La Niña periods (Araújo Júnior *et al.,* 2014). The atmospheric circulation also changes in extratropical regions with the intensification of the trade winds, which causes the obstruction and therefore a change in trajectory and intensity of frontal systems (Aragão, 1998).

Using the El Niño event of 1982-1983 as an example, Kousky *et al.* (1984) reported both the occurrence of a significant intensification of upper tropospheric subtropical jets and many blocking events at mid-latitudes. Combined, these co-occurrences favor the permanence of persistent frontal systems in southern Brazil, confirmed by Silva *et al.* (2009). These jets and blocking events can reduce the approach of these frontal systems to the region under study. This hypothesis would explain the lower incidence of S-SW waves with high significant wave height and peak period values during El Niño years (especially in winter). The south waves resulting primarily from frontal systems from the southern region should occur with greater frequency in winter. In the other hand, the South Atlantic High weakens in periods of La Niña, reducing the intensity of the trade winds and favoring the migration of cold fronts that affect the southeast.

El Niño periods also influence the coastal sediment budget through the wave climate. Fernandez & Muehe (2010) observed that the blocking of cold fronts during these periods decreased the occurrence of cold fronts on Rio de Janeiro's coast, with a consequent reduction of the wave's transposition events in the area of Massambaba Beach. That reduction inhibited the recovery of the sedimentary stock, which resulted in a negative sediment budget for those years.

Despite the variability of the wave percentages from S-SW in El Niño/La Niña years being small, we cannot forget that this is a mean pattern that does not reflect the exact number of occurrences of cold fronts, their intensity in the study area or their reflections in the wave pattern. This apparent slight increase in the percentage of waves in La Niña years, as an example, can strongly affect the coastal sediment dynamics. A higher average percentage of waves in the winter as a result of a higher occurrence of cold fronts in a short period can result in a high remobilization of sediments along the coastline without sufficient time for the replacement of these sediments. This may substantially change the beach morphology in that period.

Other interannual variability modes can influence the pattern of incident waves, such as the Tropical Atlantic Dipole. As for the ENSO in the Pacific, this is the result of variability in large-scale ocean-atmosphere coupling, centered on the southern autumn period (Souza & Nobre, 1998). In this case, the sea temperature anomalies in the surface in the Tropical Atlantic interfere with meridional circulation (the Hadley cells) and interfere in the southern shift of the ITCZ. With warmer waters in the North Atlantic tropical zone and cooler in the South Atlantic tropical zone, there is an intensification of the downflow in the southern portion of the tropical Atlantic; this causes, for example, reduced rainfall in northeastern Brazil (Aragão, 1998).

It is noteworthy that the action of these two combined events can promote variability in the responses to atmospheric circulation and consequently to the waves generated by wind in the South Atlantic, depending on the separate intensities of these events. This explains why the variability of wave parameters in an interannual analysis are only partially explained by the ONI and that the correlation values tend to be reduced.

4. Conclusions

This research aimed to detect and analyze the variability of regional wave climate from Rio de Janeiro state's central coast in relation to ENSO events. Wave model data from WAVEWATCH III (NWW3) available from NOAA were used to characterize the interannual and seasonal wave climate in the region. The model was validated here with data from an oceanographic buoy anchored in the study area and a strong correlation observed. The NWW3 data for the Rio de Janeiro continental shelf were also compared to studies in the region to validate the data.

The correlations between wave parameters and the Oceanic Niño Index (INO) had many low values, nonetheless significant, that demonstrated the existence of a relationship between the variabilities of these parameters, particularly for significant wave height. This parameter had a correlation of approximately -0.17, with a time lag of four months. It represents a small but statistically significant value. This indicated that in El Niño years, a tendency to reduce the significant wave height existed with a several month delay in the response of the local waves, while an inverse pattern occurred in La Niña years. An increase in wave incidence was observed from the S and SW quadrants in La Niña years, especially in boreal winter, causing the relative increase in wave heights values.

The lag observed for significant wave height proved consistent with values reported for the lag wind, noting that the variation in waves is to a large extent caused by the attenuation of the frequency of events from the S quadrant during El Niño periods. These events are associated with large percentage of the occurrences of frontal systems.

This pattern of reduction in significant wave heights in El Niño years is noted in the literature, attributed to the intensification of the center of the South Atlantic High combined with increase in the occurrence of subtropical jets in these periods. This results in a larger barrier to cold fronts, these being retained in the southern region of Brazil and reaching the Southeast less frequently.

Turning to the low correlation values calculated for the period and direction peak, these indicate a negligible interference or a lesser degree of reliability for interpretation as a single variable. However, the combined analysis of this parameter with the significant wave height in the directional histograms shows a consistency in the pattern observed for the different periods analyzed.

The occurrence of other modes of variability with an interannual character in the Atlantic Ocean influences the variability of the wave parameters in the regions where the ONI is responsible for only a portion of this variability; this increased the plausibility of the low direct correlation values between the series. A thorough study of the other modes of interannual variability that could influence this data will be required.

Therefore, we suggest that analysis of the waves under the El Niño/La Niña bias should continue, especially in the southern hemisphere, both in other regions of Brazil and also along the occidental African coast. This would enhance the understanding of the remote effects of wind variability in the Pacific Ocean to other regions of the Atlantic Ocean and the corresponding response of the ocean.

Appendix

Supporting Information associated with this article is available on-line at http://www.aprh.pt/rgci/pdf/rgci-570_Pereira_Supporting-Information.pdf

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Biomarkers responses in different body regions of the polychaeta *Hediste diversicolor* (Nereidae, Polychaete) exposed to copper

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Abstract

This study aims to evaluate the effects of exposure to 1 µM of copper during a period of test of 48 h, on enzymatic and lipid peroxidation biomarkers in anterior (A), middle (M) and posterior (P) body regions of the polychaeta (Nereididae) *Hediste diversicolor*. The biomarkers selected in this work were the NADPH cytochrome c reductase (NADPH red) as phase I biotransformation enzyme, glutathione-S-transferase (GST) as phase II enzyme, and the oxidative stress markers using catalase activity (CAT) and malondialdehyde accumulation (MDA). The NADPH red activity was not significantly affected by copper exposure in the different body regions. Glutathione-S-transferase (GST) was significantly augmented ($p< 0.05$) only in the A region of Cu group compared to control group. The higher and significant CAT activity ($p< 0.05$) was noted in the P region of treated group paralleled by a lack of MDA production in the same region. A higher MDA content was observed in A region compared with the same body region of treated worm supporting the idea of a highest oxidant condition in this region.

Keywords: Copper, NADPH cytochrome c reductase, glutathione-S-transferase, catalase, *Hediste diversicolor.*

Resumo

Resposta de Biomarcadores em* Hediste diversicolor *(Nereidae, Polychaete): Efeitos da exposição ao Cobre

Com este trabalho pretende-se estudar a exposição ao cobre (1 µM) em testes de 48 h, com biomarcadores enzimáticos e de peroxidação lipídica nas regiões corporais anterior (A), mediana (M) e posterior (P) no poliqueta (Nereididae) *Hediste diversicolor*. Os biomarcadores selecionados para este estudo foram *NADPH cytochrome c reductase* (NADPH red) como enzimas biotransformadoras nas reações de fase I, *glutathione-S-transferase* (GST) como enzima da fase II, e os marcadores do *stress* oxidativo usando a atividade da enzima antioxidante catalase (CAT) e a acumulação de *malondialdehyde* (MDA). A atividade do NADPH não foi significativamente afetada pela exposição ao cobre nas diferentes regiões do corpo do poliqueta. *Glutathione-S-transferase* (GST) aumentou significativamente ($p< 0.05$) na região A comparativamente com o grupo controle. A maior e significativa atividade de CAT ($p< 0.05$) foi registada na região P paralelamente à ausência de produção de MDA nessa mesma região. Maiores concentrações de MDA foram registadas na região A evidenciando uma maior condição de *stress* oxidativo nessa região.

Keywords: *Cobre, NADPH cytochrome c reductase, glutathione-S-transferase, catalase, Hediste diversicolor*

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1. Introduction

Many species of annelids are commonly used in toxicological studies. Polychaetes are the dominant macrofauna within fine sediments and the presence or absence of specific polychaetes is considered as an excellent indication of the condition of the benthic environment (Marcano *et al*. 1996; Lucan-Bouché *et al*. 1999; Carvalho *et al*., 2013). In the group of the polychaeta, many species seem to exhibit an extraordinary tolerance to various environmental contaminants, being also the most common invertebrates found in polluted areas (Eriksen *et al.,* 1988; Bouraoui *et al*., 2014). *Hediste diversicolor* is a marine annelid which lives in estuary sediments rich in microorganisms and toxic agents resulting from pollution. It has been the subject of numerous studies, focusing on diverse aspects of its biology and ecology, including a range of pollution related subjects. This polychaete is characterized by high physiological tolerance to extreme variation of many environmental parameters such as temperature and salinity (Ait Alla *et al*., 2006;) and seems to exhibit tolerance to various environmental contaminants (Eriksen *et al*., 1988).

Copper pollution in the aquatic environment results from natural and anthropogenic sources such as mine washing or agricultural leaching (Rainbow and Smith, 2013). Although copper is a trace element essential to life it is also one of the most toxic metals (Ferreira-Cravo *et al*. 2009). This metal is required for maintaining cellular function and is an integral part of a number of copper-containing enzymes. One of the main toxic mechanisms of this metal is due to the alterations in intracellular protein machinery either directly via denaturation of enzymes or indirectly via generation of reactive oxygen species (ROS) through Fenton and Haber–Weiss reaction (Furuno *et al*., 1996; Bouraoui *et al*., 2009).

The use of biomarkers has been reported to be very informative about the organism's stress response to pollutants (Jebali *et al*., 2013). NADPH cytochrome c reductase is a phase I biotransformation enzyme (CYP-dependent monooxygenase) playing a main role in the detoxification of organics xenobiotics (Arun and Subramanian, 2003). Glutathione-S-transferase (GST) is a phase II enzyme involved in the metabolism of lipophilic organic contaminants. This enzyme also plays a role in cellular protection against oxidative stress (Guidi *et al*., 2010). Catalase (CAT) is a well-known anti-oxidant enzyme, its activity increasing in organisms submitted to oxidative stress (Durou *et al*., 2007). One of the well-known lipid peroxidation products is malondialdehyde (MDA), this markers was usually used to evaluate the state of lipid peroxidation of the membrane (Alexandrova and Bochev, 2005, Ben Kheder *et al*., 2014) Polycheates are invariably exposed to pollutants. Studies examining bioaccumulation and subsequent toxicity of contaminants have often focused on whole organism. However, the interactions pollutants-different body regions are poorly known and need to be considered. Taking into consideration the existence of a differential response along the body of *H. diversicolor* and also the previous reports showing a response gradient in different body regions of annelids (Rosa *et al* 2005; Ferreira-Cravo *et al* 2009), the aim of this study was to evaluate the effects of exposure to copper on enzymatic biomarkers and lipid peroxidation level in anterior, middle and posterior body regions of *H. diversicolor*.

2. Material and methods

2.1. Animal treatment

Specimens of the polychaete *H. diversicolor*, with mass between 0.4 and 0.6g were collected from Teboulba (Tunisia), which was reported to be a clean site (Banni *et al*., 2005, 2007; Jebali *et al*., 2007; Bouraoui *et al*., 2009, 2014). The animals together with the surrounding sediments were put in polyethylene bottles. Once in the laboratory the worms were separated from sediment, cleaned from debris, and then placed in glass dishes at 14°C with aerated clean sea water to ambient photoperiod regimes for 3 days; this acclimation period was used for excluding specimens with exoskeleton or skin infections.

After this period, worms were exposed for 48 h to1 µM of Copper ($CuSO_4$). A control group was run in parallel, employing only saline water (10‰) with the same characteristics cited above. The number of worms were used per experimental group varied between 40 (control) and 50 (copper). After 48 h of exposure, the organisms were sacrificed and based on the anatomic structure, were subdivided in three regions: anterior region (A, first 20 setiger segments), middle region (M, next 20 setiger segments) and posterior region (P, the rest of the body) (Rosa *et al*., 2005). A, M or P sections were pooled into five replicate samples of 5 to 7 worms each, washed briefly in ice-cold, and conserved in liquid nitrogen until analysis.

2.2. Biochemical analyses

A pool of each region (n=5-7) were homogenized (1:5, w/v) in phosphate buffer 100 mM, pH 7.5, NaCl (2.5%). Homogenates were then centrifuged at 9000g for 30 min (4°C). The supernatant (S9 fraction) of each sample was stored at -20°C, and employed later to determine total protein content, CAT and GST activities and MDA accumulation. Subsequently, the supernatant was centrifuged at 100.000g for 50 min at 4° C. The pellet was resuspended in 10 mM HEPES, pH 7.4, containing 250 mM sucrose in 20% glycerol, to obtain a microsomal fraction. This microsomal suspension was used for NADPH cytochrome c activity measurements. Total protein content in the homogenate was measured following the Bradford method (Bradford, 1976), at 595 nm, using bovine serum albumin as standard.

2.3. NADPH cytochrome c reductase determination

NADPH cytochrome c activity was determined according to Hayes (1982). Reaction mixture contained the stock microsomal enzyme, 20 mM NADPH and 10 mM of cytochrome c. The specific activity was determined by spectrophotometric method at 550 nm. The results were expressed as nmoles cytochrome c reduced/min/mg proteins**.**

2.4. Glutathion-S-transferase determination

GST activity was assayed by the method described by Habig *et al*. (1974) using the 1-chloro-2,4-dinitrobenzene (CDNB) as substrate, and GSH (1 and 4 mM final concentration, respectively), in 100 mM sodium phosphate buffer, pH 7.5. All GST activity assays were realized in conditions of linearity with respect to incubation time. The results were expressed as nmole produced/min/mg proteins.

2.5. Catalase determination

Catalase activity was determined by the method of Claiborne (1985) measuring the rate of enzymatic decomposition of H_2O_2 determined as absorbance decrements at 240 nm. The assay mixture consisted of 750 µL of sodium phosphate buffer (0.1 M, pH 7.5 and 25°C), 200 µL solution of 0.5 mM H_2O_2 and 50 µL of cytosolic fraction. Results were expressed as µmol H_2O_2 consumed/min/mg proteins.

2.6. Malondialdehyde accumulation

Lipid peroxidation was estimated in terms of thiobarbituric acid reactive species (TBARS) with use of 1,1,3,3-treaethyloxypropane as a standard. The reaction was determined at 532 nm, using TBA reagent as described by Buege and Aust (1978). MDA content was expressed as nmoles equivalent MDA/mg proteins.

2.7. Statistical analysis

The results were expressed as means ± SD. SPSS software (version 20.0) was used for statistical analysis. The data were first tested for normality and homogeneity of variance to meet statistical demands. Data from different groups were compared by a one-way analysis of variance (ANOVA) and Gabriel's test were used to analyze raw biomarker data for comparison of responses between groups. All differences were considered significant at $p < 0.05$. Different letters a, b and c indicated significant differences between groups.

3. Results

No significant worm mortality (<10%) was observed during the exposure period. The effect of 1µM Cu on NADPH Cyt C red was reported in Fig.1. This enzymatic activity showed no differences between control and Cu groups and between the body regions ($p<0.05$). However, GST activity (Fig. 2) was higher ($p<0.05$) in the A region, both in control and Cu group in respect of the M regions and P regions. Also GST activity in the A region of Cu group was higher ($p<0.05$) than GST activity in the same body region of control group.

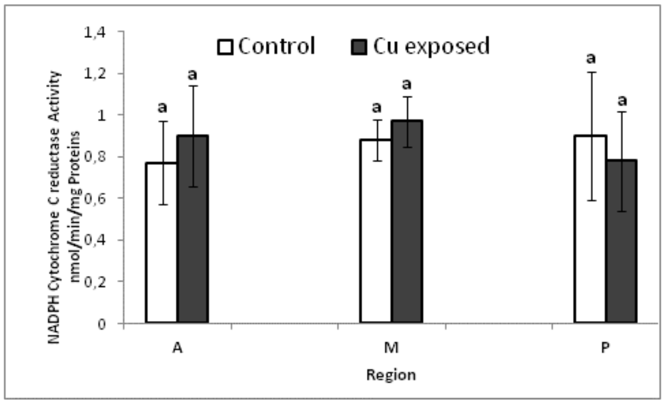

Figure 1 - NADPH Cytochrome C reductase (NADPH Cyt C red) activity in different body regions of the worm *H. diversicolor* (Nereididae) submitted to 1µM Cu. Data are expressed as means ± standard deviation. Identical letters indicate absence of statistical differences ($p<0.05$). A: anterior, M: middle, and P: posterior.

Figura 1 - Actividade da NADPH Cytochrome C reductase (NADPH Cyt C red) em diferentes regiões do corpo de H. diversicolor (Nereididae) expostos a 1µM Cu. Os dados são apresentados como médias ± desvio padrão. Letras idênticas indicam a ausência de diferenças estatísticas (p<0.05). A: anterior, M: mediana, e P: posterior.

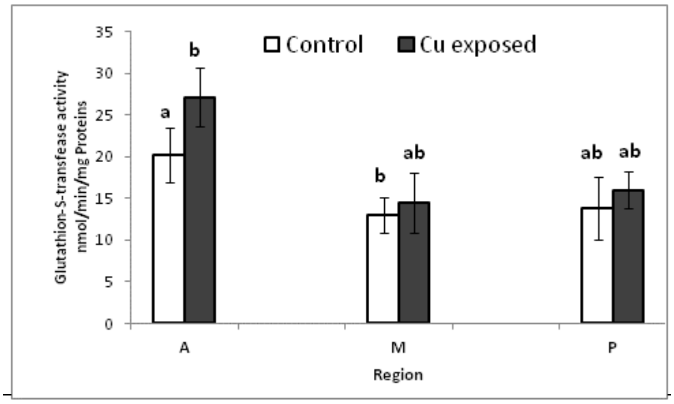

Figure 2 - Glutathion-S-transferase (GST) activity in different body regions of the worm *H. diversicolor* (Nereididae) submitted to 1µM Cu. Data are expressed as means ± standard deviation. Identical letters indicate absence of statistical differences ($p<0.05$). A: anterior, M: middle, and P: posterior.

Figura 2 - Actividade da Glutathion-S-transferase (GST) em diferentes regiões do corpo de H. diversicolor (Nereididae) expostos a 1µM Cu. Os dados são apresentados como médias ± desvio padrão. Letras idênticas indicam a ausência de diferenças estatísticas (p<0.05). A: anterior, M: mediana, e P: posterior.

In terms of oxidative stress marker, CAT activity was significantly different along the body regions of controls and treated group. It was lower ($p < 0.05$) in the A region, intermediate in the M region, and higher in the P region, both in control and Cu group (Fig.3).

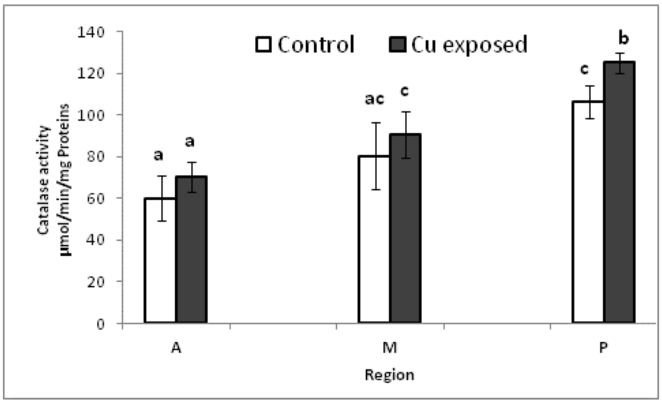

Figure 3 - Catalase (CAT) activity in different body regions of the worm *H. diversicolor* (Nereididae) submitted to 1µM Cu. Data are expressed as means ± standard deviation. Identical letters indicate absence of statistical differences (p<0.05). A: anterior, M: middle, and P: posterior.

Figure 3 - Actividade da Catalase (CAT) em diferentes regiões do corpo de H. diversicolor *(Nereididae) expostos a 1µM Cu. Os dados são apresentados como médias ± desvio padrão. Letras idênticas indicam a ausência de diferenças estatísticas (p<0.05). A: anterior, M: mediana, e P: posterior.*

Concerning oxidative damage, the posterior region presented the lower MDA content and no statistical difference ($p < 0.05$) was observed in both control and Cu groups. The MDA accumulation was significantly higher ($p < 0.05$) in A and M regions in respect of the control group (Fig.4).

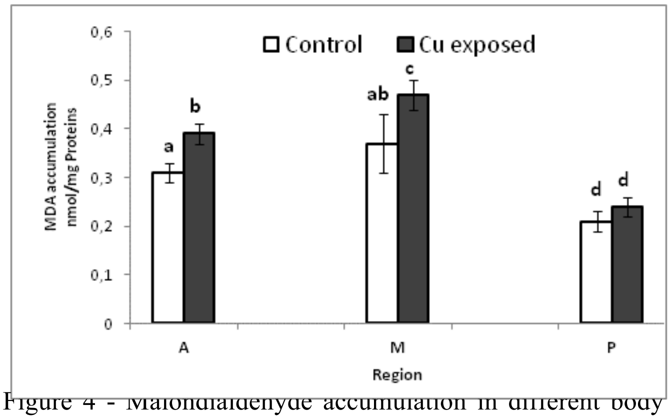

Figure 4 - Malondialdehyde accumulation in different body regions of the worm *H. diversicolor* (Nereididae) submitted to 1µM Cu. Data are expressed as means ± standard deviation. Identical letters indicate absence of statistical differences (p<0.05). A: anterior, M: middle, and P: posterior.

Figure 4 - Acumulação de Malondialdehyde em diferentes regiões do corpo de H. diversicolor *(Nereididae) expostos a 1µM Cu. Os dados são apresentados como médias ± desvio padrão. Letras idênticas indicam a ausência de diferenças estatísticas (p<0.05). A: anterior, M: mediana, e P: posterior.*

4. Discussion

The effects of metals on the polychaeta *H. diversicolor* were largely documented, however, and to our knowledge, no studies investigated the effects of subacute concentrations of copper in different body regions of the polychaeta *H. diversicolor.* The present work reported the acute effects of 1µM of Cu on anterior, middle and posterior body regions of *H. diversicolor* using a multimarker approach comprising a set of enzymatic and lipid peroxidation markers.

In this study, worms were exposed to 1 µM of Cu, this concentration was reported to be sublethal for terrestrial (Gastaldi *et al*., 2007; Hankard *et al*., 2004) and marine worms (Ferreira-Cravo *et al*., 2009). Indeed, Moreira *et al*. (2005) were reported acute toxicity of copper in *H. diversicolor*. They suggested that 48-h LC50 value was 241 ug/L and 48-h IC50 was 52 ug/L

Yang *et al*. (2012) were reported that the LC50 of Cu in polychaeta *Perinereis aibuhitensis* is approximately 475 µg/L after 96 h of exposure.

Metals as copper have been of great concern in marine and coastal ecosystems, since they cause several biological alterations from molecular to tissue level depending to their concentrations and time exposure (Banni *et al*., 2009; Ben Khedher *et al*., 2014). Therefore, they may be also, accumulated in various tissues of living organisms and lead to several orders of magnitude higher than those of the surrounding water (Ghedira *et al*., 2011; Jebali *et al*., 2014).

Toxic effects of pollutants often depend on their capacity to increase the cellular levels of reactive oxygen species (ROS). Cu was reported to create an oxidative stress status by the Harber-Weiss and Fenton reaction of Cu cations (Bouraoui *et al*., 2009; Caldwell *et al*., 2011), resulting in cellular damages due to hydroxyl radicals (HO•). Some enzymatic and non-enzymatic tests have been proved to be suitable for monitoring the effects of pollutants. In the present work, the level of NADPH Cyt C red along the body was not affected by exposure to copper. The same absence of response was observed in previous studies (Bouraoui *et al*., 2009) when this worm was exposed for 12, 24, 36 and 48h to the same concentration. Moreover, several authors were reported that the level of NADPH cyt c red could increase after exposure mainly to hydrocarbons compounds (Christensen *et al*., 2002; Bouraoui *et al*., 2009, 2010) suggesting a high increase of the organic compound metabolic processes.

Worm phase II conjugation, measured as GST activity, was significantly increased in the A region of Cu group compared to the same region in control group. It is known that GSTs constitute an anti-oxidant enzyme involved in GSH conjugation to xenobiotics, fatty acids hydroperoxides and aldehydic products of lipid peroxidation (Hermes-Lima, 2004; Jebali *et al*., 2014). The higher GST in the A region indicates a higher antioxidant capacity against peroxyl and hydroxyl radicals. In other hand, the lack of difference between control and treated group in M and P region can be explained by other antioxidant mechanisms as glutathione peroxydase (GPX) and/or superoxide dismutase (SOD). In this view, Rosa *et al*., 2005 reported high SOD and GPX activity in M and P region of *Laeoneris acuta* (anelida polychaeta) after exposure to 50 µM of hydrogen peroxide (H_2O_2) accompanied by low activity of GST in these regions.

Concerning another anti-oxidant enzyme, CAT, our result demonstrate that, in *H. diversicolor*, exposure to sublethal concentrations of Cu, induced significant changes in CAT activity only in P region. In other hand, CAT was significantly different along the body regions of controls and treated group indicating that *H. diversicolor* deals with oxidative stress employing different strategies among these body regions. Indeed and as suggested by our data, Rosa *et al*., (2005) and Ferreira-Cravo *et al*. (2009) described an increase of CAT activity in posterior region of *Laeoneris acuta* exposed respectively to 10 µM of H_2O_2 and 62.5 ug/L of copper.

The content of malondialdehyde (MDA) is a way to evaluate the lipid peroxidation level, which occurs in the absence of sufficient antioxidant defense (Guidia *et al*., 2010; Ghedira *et al*., 2011; Buffet *et al*., 2014). A Lower MDA values for posterior regions is due to a sufficient antioxidant defense such as CAT in this region. In fact, when, CAT activity was induced in P region of worms exposed to 1µM of Cu, the MDA accumulation followed a decreasing trend. A clear evidence of oxidative perturbations reported in previous studies in whole body of *H. diversicolor* treated with sublethal Cd, Cu and B[a]P proved a reduced capability to prevent lipid peroxidation generated by pollutants as metals, hydrocarbons and nanomaterials (Catalano *et al*., 2012; Bouraoui *et al*., 2014; Moschino *et al*., 2014).

5. Conclusion

H. diversicolor exposed to 1µM of Cu, presents differential biomarkers responses in the anterior, middle, and posterior region of its body: In the A region, higher activity of GST, whereas in the P region higher activity of CAT with a low MDA level. Our study can be used not only to understand the response of polychaete exposed *in situ* to copper, but also, to ensure a better sustainable management of coastal areas. However, studies with other toxicological responses (enzymatic or non enzymatic) are needed for a better understanding of the results obtained in the present work.

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Management and research on plastic debris in Uruguayan Aquatic Systems: update and perspectives

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Abstract

Synthetic plastics have become an indispensable component of modern life, and the amount of plastics disposal has increased dramatically as a result. With human population increasing, it is expected that the prevalence of plastic debris in the environment will also increase, unless sustainable daily habits are incorporated, waste management improved, and new alternative materials are discovered and popularized. To date, several reports show negative effects of plastic debris on marine and freshwater fauna (e.g. invertebrates, birds, turtles, marine mammals). Plastic are ubiquitous in the water column, deposited

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in fine sediments and enter the guts, respiratory structures and tissues of different aquatic species, and are incorporated into food webs via ingestion. This global problem also affects beach and near-shore activities (e.g. tourism, fisheries, and aquaculture) with negative social and economic consequences. The research of plastics effect on aquatic environments in Uruguay is only incipient. With the aim of contributing to scientific knowledge, decision-making and the management of plastic debris, here we reviewed the available information on plastic debris sources, their impacts on biodiversity, and policy issues in Uruguayan aquatic systems. Moreover, we reviewed and systematized community outreach initiatives, and examined national policies and management initiatives. We found that Uruguayan aquatic systems (freshwater, coastal marine and benthic) are affected by plastic pollution, both from land-based and sea-based activities, although national-level policies are modern and well suited for minimizing the impacts of plastic pollution. We reviewed biota-plastic debris interactions, and found evidence for impacts on a number of aquatic taxa, including the poorly reported ingestion of microplastics in freshwaters fishes and the association with plastic benthic debris. Global and regional hydrographic settings (Río de la Plata Estuary), as well as idiosyncratic ecological, socio-economic and cultural issues, make Uruguay a valuable test-site for this topic. Our ultimate goal is to minimize the effects of this widespread environmental, economic, health and aesthetic problem.

Keywords: Plastic and microplastic pollution, Río de la Plata, Aquatic systems, Integrated Coastal Zone Management, Waste management, Uruguay.

Resumo

Pesquisas e manejo de descartes plásticos em sistemas aquáticos uruguaios: atualização e perspectivas

Produtos plásticos tem se tornado um componente indispensável na vida moderna, como conseqüência disso a quantidade de plásticos descartados tem dramaticamente aumentado. É esperado que com o aumento da população de seres humanos a prevalência de descartes plásticos também aumente, a menos que hábitos cotidianos sustentáveis sejam incorporados, e novos materiais alternativos sejam descobertos e popularizados. Até o momento, diversas pesquisas têm mostrado os efeitos negativos de descartes plásticos sobre a fauna marinha e dulcícola (p. ex.: invertebrados, aves, tartarugas e mamíferos marinhos). Em ambientes aquáticos, plásticos estão em toda parte: na coluna de água, depositados em sedimento fino e dentro de estômago, estruturas respiratórias e tecidos de diversas espécies aquáticas, e são incorporadas nas teias alimentares através da ingestão. Este problema global também afeta atividades realizadas na praia e próximas à costa (p. ex.: turismo, pesca, e aqüicultura) com conseqüências sociais e econômicas negativas. Pesquisas que abordem os efeitos de plásticos sobre ambientes aquáticos no Uruguai é ainda incipiente. Com o objetivo de contribuir para o conhecimento científico, a tomada de decisões e o manejo de descartes plásticos, revisou-se a informação disponível acerca de fontes de descartes plásticos, observando os impactos delas sobre a biodiversidade e sobre questões políticas em sistemas aquáticos uruguaios. Além disso, revisou-se e sistematizou-se o alcance de iniciativas da comunidade, e examinou-se a política nacional de iniciativas de manejo. Descobrimos que os sistemas aquáticos uruguaios (de água doce, costeiros e marinhos bentônicos) são afetados pela poluição de plástico, pelas atividades terrestres e pelas atividades ligadas ao mar, embora as políticas a nível nacional sejam modernas e bem adaptadas para minimizar os impactos dessa poluição. Revisamos as interações biota-detritos plásticos, e encontramos evidência de impactos sobre diversos taxa aquáticos, incluindo a ingestão de microplástico per peixes de água doce, e da associação que existe entre biota e os detritos plásticos bentônica, geralmente pouco relatados. As configurações hidrográficas globais e regionais (Estuário Rio de la Plata), bem como questões ecológicas idiossincráticas, sócio-econômico e culturais fazem do Uruguai um valioso lugar-teste para este tópico. O objetivo final dessa pesquisa é minimizar os efeitos deste amplamente difundido problema de saúde, ambiental, econômico e estético.

Palavras-chave: *Contaminação por plásticos e microplásticos, Rio de la Plata, Gestão Costeira Integrada, Gestão de resíduos, Uruguai.*

1. Introduction

Plastics are a relatively new material, since the first man-made plastic was presented by Alexander Parkes at the 1862 Great International Exhibition in London (NPR, 2009). Even though the use and production of plastic date from early 20th century, its production and consumption did not really take off until after World War II (Dubois, 1972; NPR, 2009). Due to its versatility, resistance and low cost, plastics became widely used, increasing its annual global production from 1.7Mtones to 280Mtones within the last 60 years (Lechner *et al.,* 2014). Thus, in a short time, plastics have become a major component of modern debris (Andrady & Neal, 2009).

Although plastics are theoretically recyclable, a huge amount is simply dumped awaiting their natural long-lasting degradation (Moore, 2008; Barnes *et al.*, 2009). During this process plastic debris find their path to waterways and, through streams, rivers, and lakes discharge into coastal seas and oceans (Murray, 2009; Moore *et al.*, 2011; Rech *et al.*, 2014).

Plastic debris does not only come from land-based activities. For instance, fishing fleets, maritime traffic, and the increasing human populations in coastal zones are also important sources of marine debris (Ribic *et al.*, 2010). It is estimated that fishing activities are responsible for ca. 20% of plastic debris (Andrady, 2011), not only because of "throw away" behavior, but also because of fishing gears (e.g., nets, longlines) missed or forsaken at sea (Bullimore *et al.*, 2001; Tschernij & Larsson, 2003). Further, accidental dumping due to negligence of ship operators (e.g.

garbage, raw materials) are an important source of debris such as resin pellets used for plastic manufacturing (Mato *et al.*, 2001; Moore, 2008). Recreational activities also produce plastic pollution, mainly due to irresponsible individual actions, such as the deliberate release of garbage into the environment (Murray, 1996).

In this vein, plastic pollution in aquatic ecosystems is one of the most significant global environmental problems, determining multiple ecological consequences (Thompson *et al.*, 2009), which are not yet completely understood. Besides the aesthetic problem, the adverse effects on marine and freshwater fauna are evident (e.g. invertebrates, fish, birds, turtles and mammals) (Azzarello & van Vleet, 1987; Laist, 1997; Clapham *et al.*, 1999; Erikson & Burton, 2003; OSPAR, 2009; Boerger *et al.*, 2010). The most harmful consequences reported so far are related to entanglement, ingestion, and species distribution (Pierce *et al.*, 2004; Thompson *et al.*, 2009). The entanglement is probably one of the most common consequences of plastics debris (e.g. with fishing gears), affecting mobility, natural behavior and/or asphyxia (e.g., sharks, seals).

Plastic ingestion has been widely documented, and its physical consequences include asphyxia, reduced nutrient assimilation, and obstruction and perforation of digestive tracts (Derraik, 2002; Mascarenhas *et al.*, 2004; Rios & Moore, 2007; Mallory, 2008). However, less is known about microplastic ingestion and its role in aquatic trophic webs. Due to solar radiation and erosion, plastic debris suffer photochemical and mechanical degradation with time, generating milimetric to microscopic particles (Andrady, 2003; Moore, 2008; Cole *et al.*, 2011). These resulting microplastics (i.e. smaller than 5 mm, Arthur *et al.*, 2009), are of great current concern since they occur in freshwater and ocean ecosystems worldwide (Barnes *et al.*, 2009; Sutherland *et al.*, 2010; Andrady, 2011; Cózar *et al.*, 2014; Eriksen *et al.*, 2014). Recently, microplastic particles have been identified as a good substrate for Persistent Organic Pollutants (POPs) like DDT, PCBs, HCHs and nonylphenol, among others.

Although POPs usually present low concentrations in seawater, mainly due to their hydrophobic condition, these pollutants can be progressively adsorbed into plastic bits, increasing their concentration up to several orders of magnitude (Mato *et al.*, 2001; Teuten *et al.*, 2007; 2009; Frias *et al.*, 2010; Hirai *et al.*, 2011). These microplastics (and their adsorbed POPs) could be ingested by several animals such as amphipods, barnacles, clams, tubeworms, fishes and sea birds, and thus pollutants could be transferred to their tissues (Teuten *et al.*, 2007; Farrell & Nelson, 2012; *et al.,* Foekema *et al.*, 2013; Tanaka *et al.*, 2013). Therefore, the ingestion of microplastics may cause the spread of hazardous pollutants with endocrine disruptive capacities through food webs, *via* bio-magnification processes. However, current empirical evidence of this phenomenon in natural environments is not yet conclusive, and further research is needed (e.g., Koelmans *et al.*, 2014). As a consequence, POPs could climb up to the top of the food chain, and species of higher trophic levels magnify the concentration of contaminants in their tissues (Mato *et al.*, 2001; Teuten *et al.*, 2009; Tanaka *et al.*, 2013). Both the presence of microplastics in seafood and the potential toxins associated with them can pose a significant food safety hazard, but the risk estimation for humans has not been established yet (van Cauwenberghe & Janssen, 2014).

The massive increase in plastic floating debris in the marine environment may also have a significant impact on species distribution, particularly due to the transport of exotic species (Barnes & Fraser, 2003; Barnes & Milner, 2005; Murray, 2009) which could probably affect native marine diversity (Derraik, 2002). In marine environments, microplastics can moreover carry fouling organisms like diatoms, invertebrates and bacteria, creating a new pelagic habitat for these species (Reisser *et al.*, 2014). Rafting dispersal, involving organisms associated with floating objects of either natural or anthropogenic origin, is particularly relevant in a climate change scenario, where significant changes in species distribution limits are expected (Astudillo *et al.*, 2009; Bravo *et al.*, 2011; Farrapeira, 2011; Thiel *et al.*, 2011).

Despite the mounting evidence pointing at the negative consequences of aquatic and coastal plastic pollution, this pressing issue has not been analysed in the main scientific literature for our study area. In turn, and looking forward to manage anthropogenic marine debris, key information is lacking in order to contribute from science to decision making. In this vein, the objectives of this paper are to review, synthesize and summarize available data on sources, impacts in biodiversity and policy issues on plastic debris in Uruguayan aquatic systems.

2. Material and methods

2.1. Plastic debris in Uruguayan aquatic systems: an overview

With the aim of fostering an integrated and multidisciplinary approach to this issue in Uruguay, an overview of existing information has been performed. To this end, different research groups, currently working on different aspects of plastic debris, were summoned during 2014 (1st Workshop, and 1st Symposium on plastic debris in Uruguayan aquatic systems), reviewing and compiling their main results and investigations.

Given that this field of research is still incipient in Uruguay, with only a few refereed scientific papers published to date, unpublished observations and preliminary results of ongoing research were also included in this review. Although we are confident that several of these preliminary results will be published shortly, we are aware of the significant importance of peer review processes for their scientific validation. However, considering the importance of the problem addressed and the main objective of this review, we consider that the value of such observations and preliminary results justify their inclusion.

In the next section main sources and pathways of plastic debris into Uruguayan aquatic environments were analyzed. The two main origins (i.e. land and ocean) have been assessed and results are presented in three main categories: *Urban waste*, addressing waste management and landfills; *Waterways* and specially the Río de la Plata Estuary; and *Marine traffic in Uruguayan waters* based on satellite Automatic Identification System (AIS, Maltenoz Limited). In the second section the main ongoing assessments of plastic debris in Uruguay are described, covering *Coastal debris* focused on beaches, and *Benthic marine and estuarine debris* covering the Río de la Plata Estuary, and the inner (depth<50m) and outer (depth>50m) Uruguayan continental shelf. The third section refers to interactions between plastics debris and aquatic biota, while the last section, *Policy*, address international and regional agreements on marine pollution prevention, as well as Uruguayan laws and regulations on plastic management.

3.1. Sources and pathways

a) *Urban waste*

The capital city of Uruguay, Montevideo, and its Metropolitan Area has an estimated population of 2 million people, which represents more than 60% of the Uruguayan population. According to the Solid Waste Master Plan of Montevideo and its Metropolitan Area (SWMPM), urban waste generation fluctuates between 0.38 and 0.62 kg/person/day (FICHTNER-LKSUR-Asociados, 2004). In 2003, the formal system collected 850 tons/day of waste, while the informal sector was responsible for 696 tons/day. The 57% of the latter is primarily marketed for recycling and sold in neighbourhood markets, while organic materials are used for pork food or delivered to the Municipal treatment plant of organic wastes. Of the 43% remaining, 30% is finally disposed in landfills but the remaining 13% has an unknown final destination (FICHTNER-LKSUR-Asociados, 2004).

Plastic materials were the second most important element (14%) of urban waste in Montevideo and its Metropolitan Area (Figure 1), covering several categories: plastic films (10%), PET (2%), non-classified plastics (1%), and rigid plastics (1%) (FICHTNER-LKSUR-Asociados, 2004). However, plastics were not a very important item within the recycling market, reaching only the 6.2% (8,334 tons and 11,000 tons in 2003 and 2004, respectively) of the total recyclable materials (FICHTNER-LKSUR-Asociados, 2004).

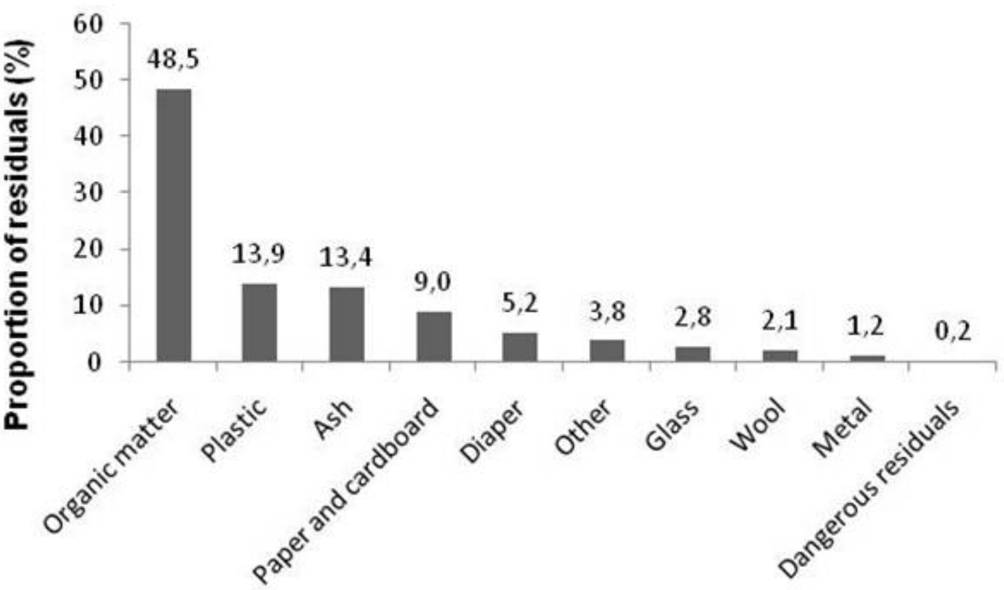

Figure 1 - Distribution of waste items in Montevideo and the metropolitan area according to FICHTNER-LKSUR-Asociados (2004).

Figura 1 - Distribuição de itens dos resíduos em Montevidéu e na região metropolitana de acordo com FICHTNER-LKSUR-Asociados (2004).

b) *Waterways*

The SWMPM also highlights another dimension to be considered in Uruguayan waste management processes: the short distance between landfills and waterways. River runoff has been identified as one of the main pathways for the entrance of anthropogenic litter from land-based sources into coastal beaches and marine environments (Derraik, 2002; Moore *et al.*, 2011; Rech *et al.*, 2014). This litter (abundance and composition) is mainly determined by land uses and social and economic activities in the basin, including transit of boats and ships, urban and rural run-off, effluents from sewage plants, and dumping at riversides (Lechner *et al.*, 2014; Rech *et al.*, 2014 and references therein).

In Uruguay, the arrival of litter in local waterways seems to occur throughout the waste management process, but especially in the final disposal of waste (e.g. open sky dumpsters or landfills). There, both the informal sector and neighbours spill debris in the waterways or along the coasts. Similarly, the growing presence of unregulated landfills near creeks and streams increases the possibility of plastic waste entering to waterways considerably (Figure 2a and 2b). Therefore, landfills would be a source of plastic materials to aquatic ecosystems, reinforced by the insufficient sweeping of cities, and the reduced awareness of the majority of the population that contributes to this contamination. This is in line with the general pattern, where plastics are the most important item in riverside litter (e.g., Moore *et al.*, 2011; Lechner *et al.*, 2014; Rech *et al.*, 2014).

The analysis of the mean distance (in meters) to the nearest river or stream for 23 Uruguayan open sky dumps showed that two of them were placed on waterways or were discharging their leakages directly into a waterway, while another 13 were placed less than 300m from the nearest stream (Figure 2c). These results could be suggesting that the Uruguay River and Río de la Plata Estuary would be directly affected by plastic contamination originated in landfills. Furthermore, the coastal area that includes these basins is the most populated area in Uruguay (i.e., 1.7 million people). Providing several ecosystem services, and holding different productive and industrial sectors, this coastal area is of utmost social, environmental, and economic relevance (e.g. tourism, fisheries).

However, from the point of view of regional management, this 'local' plastic contamination could seems 'insignificant' considering that the Río de la Plata drains the second largest basin in South America. Nonetheless, this fact cannot be used as an excuse justifying failure in waste management or passivity against this serious problem, but to increase regional (and international) collaborations regarding management of plastic debris. With more than 3,000,000 km^2, this basin is (Teuten et al., 2007; Farrell & Nelson, 2012; Foekema *et al.*, 2013 about one fourth of the continent's surface (e.g., Framiñan & Brown, 1996; Guerrero *et al.*, 1997), including areas of southeastern Bolivia, southern and central Brazil, the entire nation of Paraguay, most of Uruguay, and northern Argentina. The main rivers of the La Plata basin are the Paraná, one of the longest in the world, and its main tributary, the Paraguay River, and the Uruguay River (Mianzan et al., 2001). Although Uruguayan coastal and riverside population does not exceed 3 million persons, only Buenos Aires Province (Argentina) is home for 15.6 million people (2010). Moreover, the Rio de la Plata Estuary is also the maritime access to the 'Hidrovia', a highly complex fluvial system that communicates to the Amazon Basin, and represents a key waterway for the flow of goods and commodities between the major port cities of the region. Thus, within this hydrographic setting, Uruguayan (and Buenos Aires Province) aquatic environments, and in particular the Río de la Plata Estuary, could be considered as a sink area receiving nearly one fourth of the South American continental runoff.

This setting could be even worse if we consider that according to Acha *et al.* (2003), the Río de la Plata is characterized by a bottom salinity front that acts as a barrier accumulating debris. On average, the Rio de la Plata discharges about 23,000 m^3/s of freshwater and supply of 80x10^6 t/year of sediment into the western South Atlantic (Giberto *et al.*, 2004; Piola *et al.*, 2008). The Río de la Plata estuary is a two-layer system with a semi-permanent salt wedge and freshwater flows seawards over the surface (Burone *et al.*, 2013). This salt wedge intrusion creates a well-stratified section characterized by two salinity fronts: the bottom salinity front in the innermost part of the bottom salt wedge, and the surface salinity front in the transition between the turbid river and the less turbid marine waters.

Near the former, and generated by the opposing river discharge, incoming tide, and wave and tidal current resuspension processes, a maximum turbidity zone (MTZ) can be found. This MTZ is characterized by a high suspended matter concentration and a large portion of the transported solids can flocculate here (Framiñan & Brown, 1996; Framiñan *et al.*, 2008; Burone *et al.*, 2013). These estuarine processes may cause an increase of floating and sank debris in this area.

But these 'sink conditions' in the region can even be reinforced by oceanic processes occurring at large spatial scales in the Uruguayan Shelf. The South-western Atlantic Margin (SAM, Atlantic Ocean) is recognized as one of the most productive regions in the world, and this is mainly due to the Brazil-Malvinas Confluence (BMC), resulting from the convergence of the Southward-flowing Brazil Current (BC) and the northward flowing Malvinas Current (MC) (Ortega & Martínez, 2007; Schmid & Garzoli, 2009). This large-

Figure 2 - (a) Chacarita River (34°49'59.83"S, 56°5'23.27"W) and (b) Colorado River (34°41'32.42"S, 54°14'16.51"W) showing how landfills near streams increases the possibility that plastic wastes arrive to waterways (courtesy of Mello, L. and Grifero, L. & Teixeira de Mello, F., resp.); (c) Map showing the spatial location of urban open dumps of the major cities in Uruguay, its distance to the closest waterway (colored circles), and the population of the different Municipalities.

Figura 2 - (a) Rio Chacarita (34°49'59.83"S, 56°5'23.27"W) e (b) Rio Colorado (34°41'32.42"S, 54°14'16.51"W) mostrando como aterros perto de córregos aumentam a possibilidade de que os resíduos de plástico chegam às vias navegáveis (cortesia de Mello, L. e Grifero, L. & Teixeira de Mello, F., resp.); (c) Mapa mostrando a localização espacial dos lixões urbanos das principais cidades do Uruguai, a sua distância para a via navegável mais próximo (círculos coloridos), e a população dos diferentes municípios.

scale oceanographic process presumably traps floating items and may enhance sedimentation rates (e.g., Franco-Fraguas *et al.* 2014).

c) *Marine traffic*

Globally, ship-generated debris constitutes a major portion of garbage, mainly in remote coasts and marine seafloor (CSW, 1995; Mann, 2006). This includes debris from cargo, passenger, commercial fishing, naval, research and recreational (sailboats and yachts) vessels, and also offshore oil and gas platforms. Regarding solid waste, vessels operating at sea produce different types of garbage that can be classified into *domestic*, which includes food, food packaging and other wastes related to crew activities (e.g. cigarettes, personal care items) and *operational waste,* related to the specific purpose or activity of the vessel (e.g., packaging, fishing gears, dispensable research instruments).

As has been mentioned above, the Río de la Plata Estuary constitutes the maritime access to the highly complex fluvial system named 'Hidrovia' that communicates with the Amazon Basin and hosts the Port of Montevideo. Located in the middle of a bi-oceanic Atlantic-Pacific corridor, the Port of Montevideo is one of the main centres of cargo movement in the MERCOSUR and South America (ca. 200M inhabitants) (ANP, 2014). In this vein, as a proxy of possible ocean-based debris sources in Uruguayan waters, the number of vessels occurring in Uruguayan waters has been estimated and mapped, based on marine traffic records from the satellite Automatic Identification System (AIS, provided by Marine traffic Maltenoz Ltd). Daily positions of each vessel which operated in Uruguayan waters were considered to generate a density map based on the accumulated presences (sum of daily occurrences) in a one-year period (July 2012-June 2013) for grids of 1.0 nm side (Figure 3).

In order to sketch the composition of marine traffic in Uruguayan waters, information on vessel's type/ /category from AIS database was examined, and missing or doubtful information was checked and completed using the Maritime Mobile Service Identity (MMSI) number of each ship as a reference. Additionally, statistics on vessel arrivals to the ports of Montevideo and Nueva Palmira from 2009 to 2014 were analyzed from available data of the National Agency of Ports (ANP) website (ANP, 2014).

Based on AIS data for the period June 2012-July 2013, 4,756 different ships were recorded operating in Uruguayan waters, with a monthly average of 1,157 ships. Regions of high intensity of traffic were mainly associated to the port and 'Hidrovia' access, services and power connection areas, as well as fishing grounds (Figure 3). Vessels operating in Uruguayan waters in this period were mostly cargo vessels (77%, e.g., container, bulkers, tankers, and other transporters), Industrial fishing vessels (8%), port service ships (6%, e.g., pilots, tugs, port tenders and other small ships), and

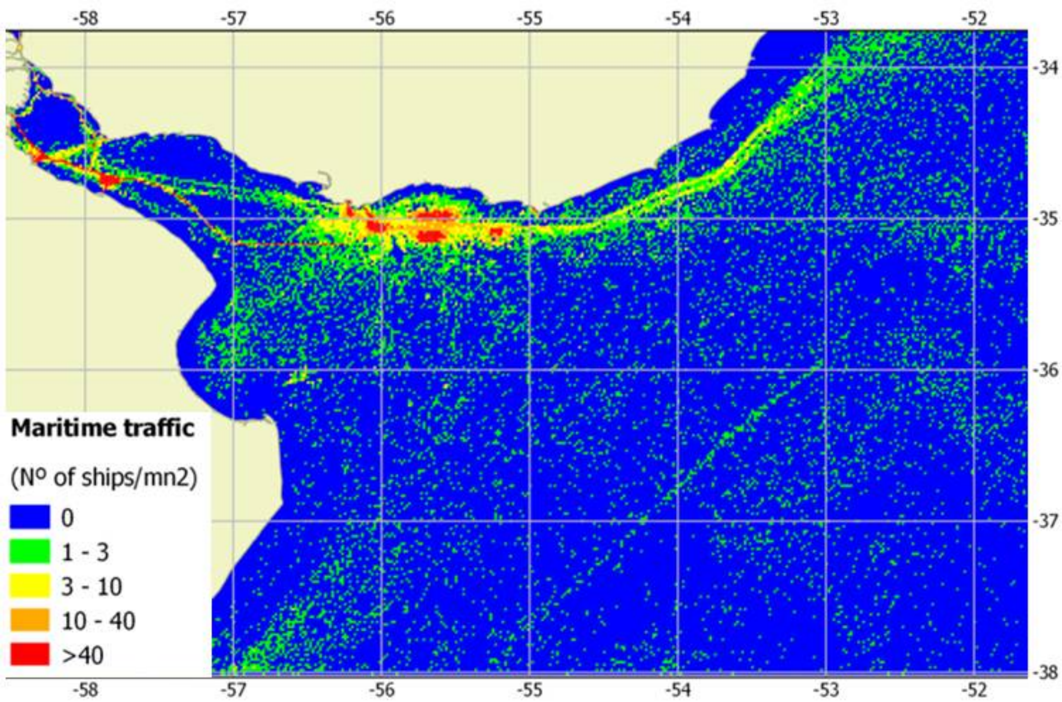

Figure 3 - Density map of vessel occurrences in Uruguayan waters represented as the accumulated daily presences of ships from June 2012 to July 2013 per cell (1.0nm side).

Figura 3 - Mapa de densidade das ocorrências de navios em águas uruguaias, representadas como as presenças diárias acumuladas de navios a partir de junho de 2012 a julho de 2013 por célula (1,0 nM per lado).

Table 1 - Categories of vessels operating in Uruguayan waters for a year-round period (July 2012 to June 2013) obtained from satellite Automatic Identification System (AIS).

Tabela 1 – Categorias de navios operando em águas uruguaias ao longo de um ano (Julho de 2012 a Julho de 2013). Dados obtidos pelo sistema satelitário de identificação automática (AIS).

Categories of ships	Number	%
Cargo vessels	3,649	76.7
Commercial fishing	389	8.2
Port service (*Pilot, port tender and tug vessels*)	274	5.8
Passenger	114	2.4
Recreational boating	105	2.2
Uruguayan army and coast guard	75	1.6
Undetermined	60	1.3
Research and other offshore vessels	35	0.7
Dredger	30	0.6
Offshore oil and gas operations	25	0.5
TOTAL	**4,756**	**100**

passenger ships (2%, e.g., high speed ferries and cruises) (Table 1).

In the period 2009-2013 there were in average 4,600 annual arrivals to the Port of Montevideo with an annual mean of 55Mgross register tonnage (GRT, ANP, 2014). For this period, arrivals included industrial fishing vessels (40%), container vessels (19%) and passenger ferries (15%). In terms of GRT the 60% was composed of container ships and 11% by cruises. The ca. 750 artisanal fishing boats operating in the Uruguayan coast of the Río de la Plata and the Atlantic Ocean (Puig *et al.* 2010) should also be considered. Although having a smaller size than the industrial fleet, artisanal fisheries might also be an important source of plastics debris especially in the coastal zone.

The international shipping regulation (MARPOL Annex V) prohibits the dumping of plastics in the sea by all types of ships, regulates the disposal of other garbage (food, domestic and operational wastes) and requires ports to provide garbage reception facilities for them (see *International agreements on marine pollution prevention* in the next section). Actually, waste is removed from the port by private companies, and transported to the municipal landfill of Montevideo. Currently lacking, accurate estimates of the amount of garbage produced in the sea, the proportion discarded at sea, incinerated onboard as well as landed for final disposal, are necessary for the development of waste management plans and actions by municipal and port authorities. These are of utmost importance taking into account that the port of Montevideo is developing a regional logistics strategic project that will strengthen its position as a regional hub port (Uruguay XXI - Sector Logístico, 2013).

3.2. Assessments of plastics debris in Uruguay

a) *Coastal debris*

The Ocean Conservancy's International Coastal Cleanup Day is carried out in almost 100 countries all over the world. In its reports, 43 items are listed in five debris-producing activities (i.e., Shoreline & Recreational, Ocean/Waterway, Smoking-related, Dumping, and Medical/Personal hygiene), according to the behavior associated with the production of debris. In Uruguay, *Shoreline & Recreational* activities account for 74% of the total items collected, while *Ocean/ /Waterway* account for the 7%.

In this line, most of plastic debris in Uruguayan urban coastal environments (i.e. those sampled in the Coastal Cleanup Day), are likely coming from autochthonous sources. By quantitative comparative purposes, data from the Ocean Conservancy's Coastal Cleanup Day 2011 were used to generate a Standardized Ocean Trash Index (SOTI). In order to account for country-level biases, area and volunteer effort were included in a single index. Thus, the SOTI results represented in Figure 4 show the total weight of debris (in pounds) collected per coastal mile, per volunteer, per day.

According to the results, Uruguay seems not to be among the countries most affected by the presence of coastal debris. However, these results are just for certain locations, on a certain day, and without considering e.g. the frequencies of beach cleaning activities which are yearly (or even daily) performed. Thus, even when the Coastal Cleanup Day is important to raise awareness about waste and plastic debris in aquatic and coastal systems, these estimates may not be a meaningful proxy of the amount of debris at a country level basis. It seems therefore crucial to supplement these results with scientific studies that quantify plastic and other debris on beaches, consider official data of mechanical cleaning in major urban beaches, or adopt a watershed-based approach including rivers arriving to the coastal areas.

In this regard, results from a project currently conducted on beaches of Punta del Este (Maldonado, Uruguay) suggest that in agreement with other studies (e.g. Martins & Sobral 2011; Portz *et al.*, 2011; Jayasiri *et al.* 2013), the smaller fraction plastics debris (i.e. microplastic <5 mm) are widely represented at beaches (Weinstein *et al.*, 2014a; b). Besides evaluating the distribution, type and volume of microplastics, this project will address for the first time the link between persistent organic pollutants (POPs) and the plastic particles in Uruguayan beaches (Weinstein *et al.,* 2014a; b). This connection has not been addressed in the context of waste management in Uruguay, but has already been highlighted internationally (e.g. Frias *et al.* 2010; Hirai *et al.* 2011; Heskett *et al.* 2012; Antunes *et al.* 2013).

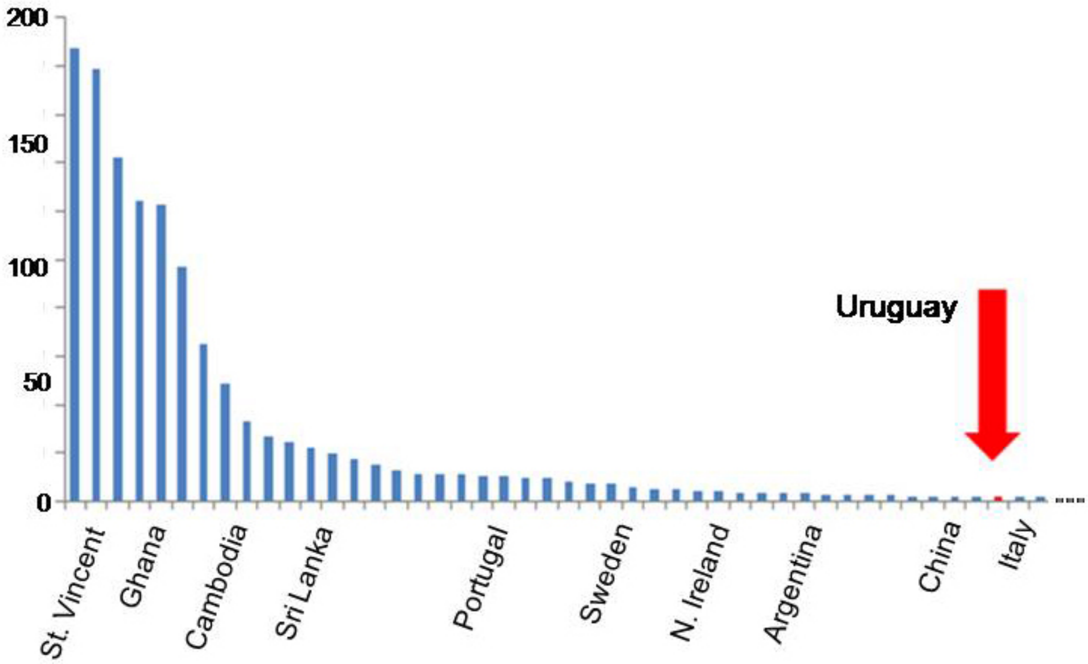

Figure 4 - Histogram showing the global Standardized Ocean Trash Index (SOTI), based on information collected by volunteers during the Ocean Cleanup Day 2011. The arrow indicates were Uruguay ranks in relation to other countries. See text for details. Data available from http://www.oceanconservancy.org

Figura 4 *- Histograma mostrando o Índice Global Padronizado Oceano Trash (SOTI), com base em informações coletadas por voluntários durante o Cleanup Day Oceano 2011. A seta indica o lugar que ocupa Uruguai em relação a outros países. Veja o texto para mais detalhes. Dados disponíveis a partir de http://www.oceanconservancy.org*

b) *Benthic debris characterization and quantification*

In order to quantify and characterize benthic marine debris in the Atlantic Ocean and Río de la Plata Estuary, the National Direction of Aquatic Resources (DINARA) has been recording marine debris collected by bottom trawl during fisheries assessment surveys since 1999 (González *et al.,* 2014). During these surveys, trawled marine debris of large and very large sizes (i.e. >10cm) were recorded and classified by material and usage, while associated organisms were also recorded. Earlier data (1999 to 2012) recorded mainly the conspicuous objects, while from 2012 to date a systematic observations of debris were performed, including also small pieces.

Overall, 430 objects have been collected in the 474 trawls performed during 11 surveys (5 in the inner and 6 in the outer continental shelf, i.e., in depth >50m) conducted from 1999 to 2013. Results have shown plastics as the most abundant debris on the seafloor, representing the 83% of benthic debris in the whole area, with a minor proportion of glass, manufactured wood, textile, rubber and others. Regarding debris classified by its usage, proportions were dependent on the zone (inner or outer continental shelf) with a higher proportion of packaging objects (containers, plastic bags, bottles, etc.) in the inner zone (72%) than in the outer one (34%), where objects associated to fishing activities were dominant (47%). This is in agreement with previous regional studies, where the main items found in riverside and estuarine bottoms were plastic bags (55% of total items), assorted plastics (22%) and cans (5%) (e.g., Acha *et al.* 2003). The presence of debris associated with marine traffic suggests the ineffectiveness or low enforcement of international regulations in Uruguayan waters (e.g., MARPOL). Continuous monitoring of benthic items and its sources is critical in order to assess and improve the enforcement of these regulations.

c) *Interactions among plastic debris and aquatic biota*

Although studies covering plastic pollution are quite recent in Uruguay, there is information available on impacts on the marine biota, and ongoing research on this topic. First known reports of anthropogenic residuals in the digestive tract of aquatic animals for the region were made in 2001 (Calvo *et al.* 2003; Rios & Feijoó, 2007). These authors found that, during 1999-2001 and 2005-2006, 11.5% of 26 stranded juvenile green turtles (*Chelonia mydas*) had debris in their digestive tracks. It was not until a couple of years later that Murman *et al.* (2011) and Vélez-Rubio *et al.,*

(2013) found that green turtles could be impacted more than expected by plastic pollution. Plastic debris, were found in more than 70% of the analyzed individuals and ingestion of solid waste items was the main cause of death of stranded specimens, even exceeding deaths caused by interaction with fisheries (Alonso & Vélez-Rubio, 2011; Vélez-Rubio *et al.*, 2013). Furthermore, juvenile individuals (i.e. carapace length < than 35cm) were the most affected by this interaction (Murman *et al.*, 2011; Vélez-Rubio *et al.*, 2013). The same pattern was also observed regionally in juvenile green turtles in Argentina (González-Carman *et al.*, 2014) and in the Río de la Plata Dolphin (*Pontoporia blainvilei*) (Denuncio *et al.*, 2011) in Argentina. These authors conclude that this phenomenon is due to the great availability of debris in the Río de la Plata estuary, especially in the turbidity front area. Moreover, the younger the individual the lower its capacity to distinguish between plastics and real food (Denuncio *et al.*, 2011; González-Carman *et al.*, 2014).

Recently, the analysis of 806 pellets of a Kelp Gull (*Larus dominicanus*) colony located on Isla de las Gaviotas (on the coast of the Río de la Plata) between 2011 and 2013, showed that inorganic matter was the third most important item in percentage of frequency of occurrence. Moreover, plastic debris represented the 60.2% of the total weight of this inorganic matter. In addition, the latter were the third most important item in percentage of frequency of occurrence (Burgues *et al.* 2014). But coastal seabirds are not the only group affected by plastics ingestion. A recent conventional diet analysis from 128 *Diomedea* and *Thalassarche* albatrosses incidentally caught in fisheries operating in Uruguayan (mainly in the shelf break and deep waters) and adjacent waters of the South-western Atlantic Ocean showed that 16.4% of the digestive tracts had marine debris (Jiménez *et al.* 2014). The most common type was plastic fragments, but some fisheries-related items were also recorded.

Although there are no published studies for Uruguay reporting plastic ingestion on marine fishes, plastic ingestion has been recently addressed on a community of freshwater fishes. A study on the fish food web in Barra Falsa Stream, a watercourse that flows into the outer Río de la Plata (Maldonado-Uruguay) revealed the presence of microplastics in the digestive tracts of eight species (Machín *et al.* 2014). Detritivore and omnivore species were the ones who showed the highest numbers of plastic debris. The presence of plastic debris in the digestive tracts was significantly greater in fishes collected during winter than in those collected in summer, probably due to changes in food availability. This is the first record of plastic debris in the diet of freshwater fishes in Uruguay.

Anthropogenic debris, from both land and marine-based sources, also constitute abundant, persistent and highly buoyant substrata attractive for varied biota (Thiel & Gutow, 2005a; Murray, 2009). This biota includes both facultative (i.e. inhabitants of benthic substrata in the coastal zone that can colonize floating objects) and obligate rafting species (i.e., only present on floating objects and sometimes on megafauna) (Thiel & Gutow, 2005; Scarabino *et al.*, 2014). Published data of biota associated with floating substrates is scarce for Uruguayan waters although their presence in the Uruguayan coast, notably on anthropogenic debris, is a very common phenomenon. Anthropogenic debris colonized by this fauna is likely related to subtropical waters, both because of the fauna involved is typical of these waters, as well as it usually matches the occurrence of blue plankton stranded in the Uruguayan coast (i.e., austral summer, during maximum influence of Subtropical waters in the area). Among obligate rafting taxa recorded, the following are highlighted for their abundance and/or singularity: *Lepas*, *Planes* (Crustacea Cirripedia and Decapoda), *Fiona*, *Litiopa* (Gastropoda) and *Amphinome* (Polychaeta). Moreover, there is a recurrent presence of facultative species of *Caprella* (Amphipoda), *Obelia* (Hydrozoa), *Conopeum* (Bryozoa), *Amphibalanus*, *Megabalanus* (Cirripedia) and *Stylocheilus* (Gastropoda) (Scarabino *et al.*, 2014). For Hydrozoa, the only taxonomic group analysed in detail, three species of hydrozoan polyps were reported (mostly represented by *Obelia dichotoma*) associated with anthropogenic floating objects (mainly plastics) stranded on the east coast of Uruguay (Leoni, 2014). These are within their reported distributional range (Genzano, 1994, Genzano *et al.*, 2009, Miranda *et al.*, 2011) and occur also on natural hard substrata in the study area (Milstein, 1976; Leoni, 2014). Two byssate bivalves, *Pinctada imbricata* and *Isognomon bicolor*, have been found in several occasions associated to floating debris in the Uruguayan coast (i.e., ca. 34° S) (Breves *et al.*, 2014; Marques & Breves, 2014). Both species live otherwise attached to natural substrata on rocky shores in the north of Santa Catarina, Brazil (28° S), being *I. bicolor* an invasive species along the Brazilian coast. None of these species have been found on rocky shores of Uruguay, thus underlining the importance of rafting as a potential dispersion mechanism for invasive species.

The manifold increase of floating debris in the marine environment in the last decades could expand the range of distribution of many marine species (Thiel & Haye, 2006) or enhance the dispersal of exotic species, with negative effects on native marine biodiversity (Derraik, 2002; Barnes & Fraser, 2003; Bax *et al.*, 2003; Barnes & Milner, 2005; Murray, 2009). We thus stress the importance of conducting detailed taxonomic and faunistic studies and quantitative analysis of this fauna and its temporal dynamics in order to elucidate the origin and dispersal of floating debris on the coast.

Regarding the colonization of benthic debris by invertebrates, isolated observations in the inner and outer Uruguayan shelf (including the Río de la Plata) during 1997-2007, and a systematic record between 2010 and 2013, showed contrasting patterns. Large (more than 15-20cm) and rigid debris (mainly plastic containers) were inhabited by a diverse epibenthic assemblage in the inner shelf, similar to that found colonizing natural substrata. However, in the outer shelf a poor (mainly anemones) and different assemblage from the natural microsubstrata (mainly shells) was present on the sunken buoys, bottles and containers found. The former includes polychaetes (mainly the serpulid *Hydroides sp.*), barnacles (*Amphibalanus sp.*), incrusting bryozoans, bivalves, polyplacophorans, sessile gastropods (the calyptraeids *Crepidula sp.* and *Bostrycapulus sp.*) and even large gastropods ovipositioning (*Cymatium parthenopeum* and the exotic *Rapana venosa*) and small octopuses (*Octopus tehuelchus*) living inside the debris. On the other hand, small (less than 15-20cm) and/or flexible debris (i.e. nylon, ropes, fabric), were colonized in both inner and outer shelf by fast growing organisms benthic invertebrates or juveniles mostly mytilids, barnacles (*Amphibalanus sp.*) or hydroids.

3.3. Policy

a) *International agreements on marine pollution prevention*

On a regional scale, there are two relevant bi-national treaties with Argentina, one concerning the Uruguay River, which addresses the uses of the river and pollution issues, and another about the Río de la Plata and its Maritime Front. The latter has been incorporated as National Law N.° 14,145 in January 25th 1974. In this law, Article 49 requires the parties (Argentina and Uruguay) to prevent water pollution. In this line, the Executive Order N°100/991 (1991) "Regulations governing use of water, coastal and port areas" (Articles 38 and 118) empowers the National Maritime Authority to impose fines for pollution caused by garbage.

On an international scale, Uruguay is signatory of the "International Convention for the Prevention of Pollution from Ships (1973), as modified by the Protocol of 1978 (MARPOL 73/78)". Therefore several national regulations have been adopted on this issue as the National Law N°14,885 (April 25th 1979). In this line, and in accordance with Regulation 9 Annex V of this international convention, the Uruguayan Maritime Provision N° 80 establishes the "rules to prevent pollution by dumping waste from ships operating in waters under national jurisdiction". Plastic is recognized as a distinct garbage type, and deliberate dumping is banned in all aquatic environments, including inland water bodies. Therefore, each discharge operation or completed incineration must be registered, including discharges at sea, at reception facilities, or in other ships. If any accidental or exceptional garbage discharge occurs, the accident time, position (or port) of the ship, the estimated amount and category of garbage, and circumstances of disposal, escape or loss must be reported.

In addition, in 1982 Uruguay signed the United Nations Convention on the Law of the Sea (UNCLOS) that sets the legal framework within which all activities in the oceans and seas must be carried out. In this sense, Uruguay incorporated this UN Convention with the national Law N°16,287 (July 29th 1992), and the national Law N°16,688 (26/XII/94) that includes a "Prevention and Surveillance Scheme to possible contamination of the waters of national jurisdiction", which in its Articles 2 and 3 clearly defines the responsibilities for protection of aquatic environment.

b) *National legislation on plastic management*

The Uruguayan law recognizes that the main problem of plastics is management (i.e., collection, final disposal, recycling), and the economic costs associated with it. The costs of this management are transferred from producers and consumers to the society as a whole. In Uruguay, local governments are responsible for waste collection and final deposition. Thus, when waste amount increases their expenses increase as well, leading us to what classical economy identifies as negative externalities of a productive activity (Pigou, 1920). How and who should bear these costs is an issue that has generated different analyses, although there is still no scientific consensus on the topic.

The Uruguayan regulatory framework on plastic disposal was inspired on European Directives, and especially on the Spanish Packaging Act (i.e., European Parliament and Council Directive 94/62/EC on packaging and packaging waste) (Parliament of Uruguay Act, 2004). Here, plastic is not considered a domestic (or consume) waste but an industrial debris. Hence, manufacturers are not only responsible for the waste generated by the industrial activity, but also of debris generated by manufactured and sold products (i.e., Extended Producer Responsibility).

In this context, Law N° 17,849 (29/11/2004) declares in the public interest the protection of the environment against damages arising from plastic waste management, enabling the limitation of individual rights as the environment is protected by the Constitution. Thus, the principles of the Uruguayan environmental policy framework set forth in the Environmental Protection Act (N°17 283) expressly incorporate prevention and forethought, gradual and progressive inclusion, social participation from various sectors, adequate environmental information, and international insight. This law involves post-consumption regulations, but also restricts their use. The Ministry of Housing, Spatial Planning and Environment (MVOTMA) is empowered to adopt measures to select the most appropriate packaging types with the least environment impact and thus prevent waste generation, "...promoting the reuse, recycling and other forms of recovering packaging waste, in order to avoid or reduce their disposal, especially as part of the common or domestic solid waste" (Article 1).

The Ministry of Housing, Spatial Planning and Environment (MVOTMA), National Customs (Ministry of Economy and Finances) and Local Governments are responsible of both enforcement and control of this law. The standard refers to packaging and packaging waste placed on the market and generated in Uruguay, including imported plastic. MVOTMA will establish terms and conditions for the implementation of the mandates of the law. Not all containers have the same environmental consequences, the same urgency, or the same treatment priority. Hence, the law provides room for future management development, empowering MVOTMA to refine the law (e.g., by product type, packaging or region) establishing adjustment periods, adequacy and effectiveness. However, packaging and waste that are exclusive of industrial, commercial or agricultural activities are subject to specific regulations (Decree N° 152/2013 and 182/2013).

The law considers several stakeholders, with obligations for consumers, manufacturers and packers, including packaging importers. On the other hand, with fewer responsibilities, sellers and transporters of plastic-packaged goods are also included. Thus the law seeks to involve all actors, activities or actions related to plastic, in order to assign responsibilities in a more equitable way and improve efficiency in implementation. In this line, is necessary to be registered at the MVOTMA to sell and purchase plastics products and/or raw material for its manufacture. This seeks to identify the manufacturing chain of packaging for all economic stakeholders, as well as to gain knowledge about final users via manufacturer's sales information. In addition, manufacturers, importers and packers registered will be responsible to implement a management plan to ensure the proper disposal of plastics once put on the market. Those who were not registered, nor have an approved management plan complying with objectives established in regulations (i.e. reduce generation of containers, re-use, recycle) will not be able to commercialize their products in the market. To guarantee this, Articles 10 and 11 of Law N° 17,849 established controls and sanctions prohibiting import, manufacture and marketing of plastics, as well as severe fines if these obligations were not met.

4. Conclusions and perspectives

Here we show that, despite the limited social awareness, Uruguay is not an exception to the global environmental issues associated with plastic debris in aquatic systems. This review highlights urban wastes (e.g., open sky landfills) as the main source from land of plastic debris, and the urgent need to improve its management. Montevideo and its Metropolitan Area are the main source in Uruguay, with plastics being the second most important type of residue (i.e., 14%). While waste management is a key aspect on plastic debris destiny, both the reduced distance between landfills and waterways, and the open dumps seems critical for Uruguayan waste management processes. Landfills are a constant source of plastic materials to aquatic ecosystems. Industry is also an important waste generator. In some cases, plastic production is not significant and is recycled and reused (e.g., tanneries, wool washers, paint factories, telecommunications, agrochemical industry) (FICHTNER-LKSUR-Asociados, 2004). However, in some cases, plastic waste is not processed and disposed properly, releasing highly toxic chemical waste or becoming a source of contamination of waterways (e.g., transported via streams and rivers), and the Río de la Plata Estuary. This debris arrives to the ocean, increasing its dispersion, and thus their impacts on biodiversity.

Furthermore, plastics also come from the ocean. Maritime traffic in Uruguayan waters has increased in the last years, and it is known that vessels generate much of the debris found in remote coasts and the seabed. In the last year the Uruguayan maritime zone received almost 1,160 ships per month, and this should be of concern. Continuous monitoring programmes of benthic litter and its sources are critical in order to assess the effectiveness of the international regulations. Also, accurate estimates of the amount of garbage produced by those ships are necessary for the development and improvement of waste management plans of municipalities and port authorities. Thus, although Uruguay has an updated and modern legislation on plastics, it remains necessary to avoid oversight and enforce proper waste management. Education and awareness of final users, whose importance should not be neglected, should also be prioritized, as well.

Watersheds and coastal areas should be managed as a whole. But besides this ‘spatial integration’, plastic waste problems should be also treated in an interdisciplinary and integrated framework, calling civil society, private companies, NGOs, decision makers (local and national) and academia. While, as has been showed, there are currently several projects under development in the country, collaboration and coordination between these is essential and should be encouraged. Information, dissemination and research on plastic debris and its consequences on the environment must be urgently addressed.

In Uruguay, institutional public awareness efforts in coastal areas are mainly headed by the EcoPlata Program. This program is now incorporated in the Environmental National Agency (DINAMA-MVOTMA), and joined the International Coastal Cleanup Day since 2009 as the national coordinator. This international event is organized by Ocean Conservancy since 1986, and is currently developed in more than 150 countries. This activity focuses on community engagement, with hundreds of thousands of volunteers worldwide spending a day collecting garbage in their local beaches. Volunteers register the type and amount of residues found and thus generate information that is systematized and shared globally.

However, this information and dissemination efforts should be complemented and based on 'ad hoc' scientific knowledge. Although studies on plastic pollution are quite recent in Uruguay, there is some information available on its impacts on the marine biota. Even if this subject is not fully considered by ecologists as a priority research (Ivar do Sul & Costa, 2007) and most biologists involved used to be focused on charismatic species (e.g. birds, sea mammals, sea turtles), this trend is changing in the last years. Research assessing effects of plastic wastes in the ecology of ecosystems provide key information that may be critical for management and mitigation of their effects. Therefore, scientific research on this topic should be promoted, since the generated knowledge is of great importance for the (near) future when inevitably this risk will be addressed in Uruguay. It is particularly important to consider integrated and interdisciplinary approaches, looking at the big picture and the several dimensions of the problem, even if the most paradigmatic are related to environmental or marine and coastal management.

Probably the main problem of plastics debris is that the costs of its management are transferred from producers and consumers to society as a whole. However, although the Uruguayan legislation recognizes that fact and includes modern and internationally recognized concepts on plastic management, the real application of established incentive, control and enforcement capability legally available seems very shy. In this sense, the situation in Latin America would not be much different, so inter-state initiatives to reduce the probability of plastic arriving to aquatic ecosystems seems also necessary.

Simply stated, the most straightforward solution to the plastic debris problem should be minimize or stop the input of non-degradable plastics in aquatic systems. In this line, we stress that the global and regional hydrographical setting, as well as idiosyncratic ecological, socio-economic and cultural issues, makes Uruguay a valuable test-site to assess: a) the relative importance of international, regional and national-level policies in plastic debris quantity and quality, b) the impact of initiatives to keep track on the source, dynamics and impacts of plastic and microplastic debris in aquatic systems in the context of a watershed dynamics, c) the level of public engagement with this policies, and d) impacts on biodiversity and ecosystem goods and services.

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Tide and Tidal Currents in the Cape Verde Archipelago *

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ABSTRACT

The hydrography and oceanography in deep ocean areas are expensive if based only upon fieldwork and, as a result, countries with smaller financial resources have few data from in situ measurements. This work aims to contribute to demonstrate that based on little local information it is possible to increase our knowledge through the use of numerical models. This paper describes a study of the tidal propagation in the Cape Verde Islands region and the currents induced by the tide assesses the importance of the wind for the circulation using the numerical model MOHID in a two-dimensional mode. The bathymetric data were extracted from the database of NASA SRTM 30 (Shuttle Radar Topography Mission) and the coast line was extracted from the database of NGDC (National Geophysical Data Center). The tide along the oceanic boundary of the model was imposed using the results from the FES2004 model and the wind was imposed using the GFS (Global Forecasting System) meteorological model results. The modeling system is based on a regional scale model with a spatial step of 6 km (level 1) in which two models with a spatial step 3 km (level 2) were fitted to detail the results of the flow in shallower areas of greater morphological complexity where a 2D model and reproduce the effect of wind forcing. Comparison between computed and measured levels in a station located in Palmeira harbor, Sal Island – the only available measuring station - for the year 2000, shows that the model is able to represent the tide in this location. The model results also show that the currents in the shallower areas along and between islands are very sensitive to the atmospheric forcing, suggesting that this sensitivity may extend to zones of greater depth in the presence of vertical stratification.

The residual circulation is the main product of this study with interest for coastal management. It is a completely new result, about which there was no information either from field work or from other models.

Keywords: Hydrodynamics, modelling, tides, tidal currents.

RESUMO

Marés e Correntes de Maré no Arquipélago de Cabo Verde

A hidrografia e a oceanografia de zonas oceânicas profundas são áreas de trabalho dispendiosas e consequentemente em países com menores recursos financeiros existe normalmente maior carência de dados “in situ”. Este trabalho pretende contribuir para demonstrar que com base em pouca informação local é possível aumentar de forma económica o nosso conhecimento através da combinação de dados e de modelos matemáticos. No presente trabalho é efectuado um estudo da hidrodinâmica forçada pela maré na região do Arquipélago de Cabo Verde e é a analisada a sensibilidade da solução ao vento. O trabalho é baseado no modelo numérico MOHID em modo bidimensional. Os dados batimétricos foram extraídos da base de dados da NASA SRTM 30 (Shuttle Radar Topography Mission) e a linha de costa foi extraída da base de dados do NGDC (National Geophysical Data Center). A maré na fronteira oceânica do modelo foi imposta utilizando resultados do modelo global de

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maré FES2004 e o vento foi imposto utilizando resultados do modelo meteorológico GFS (Global Forecasting System). O sistema de modelação é baseado num modelo de escala regional com passo espacial de 6 km (nível 1), no qual foram encaixados dois modelos de passo espacial de 3 km (nível 2) para detalhar os resultados do escoamento em zonas de menor profundidade - e maior complexidade morfológica – onde o vento tem afecta o escoamento em toda a coluna de água e pode ser representado por um modelo 2D.

Os níveis de maré calculados pelo modelo foram comparados com os únicos dados de marés existentes, numa estação localizada no Porto de Palmeira, ilha do Sal para o ano de 2000. A comparação dos resultados do modelo com os dados mostra que o modelo representa corretamente os níveis de maré neste local. Os resultados do modelo mostram também que as correntes nas zonas menos profundas – zonas costeiras e canais entre ilhas - são sensíveis ao forçamento atmosférico, sugerindo que esta sensibilidade poderá estender-se a zonas de maior profundidade na presença de estratificação vertical.

A circulação residual em torno das ilhas é o principal produto deste trabalho, com interesse directo para a gestão costeira e sobre a qual não existia nenhuma informação para a região, nem proveniente de medições, nem de outros modelos.

Palavras-chave: Hidrodinâmica, modelação, marés, correntes de maré.

1. Introduction

The Cape Verde archipelago located in the Atlantic Ocean, West African coast, is formed by ten islands and belongs to the sub-Sahelian zone. The climate, influenced by the Sahara desert, is dry encompassing two main seasons: a short rain season and a long dry season characterised by constant winds and haze coming from the Sahara desert.

The archipelago was discovered in 1460 by Diogo Gomes at the service of the Portuguese crown and since then, Cape Verde has been at the crossroads of international maritime routes, due to its strategic location. The archipelago also provides bathing areas and attractive tourism activities and its fisheries are an important source of food and jobs. For these reasons increasing attention is being given to the maritime issues by national authorities, although the knowledge about the local ocean circulation in the archipelago of Cape Verde remains scarce. The lack of field surveys and monitoring studies do not allow knowledge building based on data. In this context, numerical models can be used to identify the main processes responsible for the local hydrodynamics and biogeochemical processes creating a background to implement new studies based on field work and on remote sensing.

This paper describes the results of a bi-dimensional (2D) implementation of the numerical model – MOHID (Neves, 2013) - used to simulate the hydrodynamics forced by the tide the in the Cape Verde Archipelago and to assess the role of the wind in shallower areas. Using nested techniques, higher resolution results could be produced to refine the solution in shallow regions of higher topographic variability and/or under higher anthropogenic pressure. Water level data is available at Porto de Palmeira in Sal Island for the year 2000 and this information was used to validate the model results. Wind forcing was specified using GFS wind fields available on the internet (www.nodc.noaa.gov).

The Cape Verde sea is a deep oceanic region and consequently the density stratification of the water column is determines the hydrodynamics of the region as a whole. However islands and the ground elevation between groups of islands are barriers to the tidal propagation that generate important tidal velocities that deserve to be studied. These transient velocities generate residual flow that is the combination of the effects advective inertia and Coriolis inertia (see Huthnance, 1973 and Pingree and Maddock, 1980) that be quantified only by mathematical models. This residual determines the net displacement of anthropogenic discharges and is important for coastal sediment dynamics.

The importance of the residual flow along and between islands associated to the tidal propagation justifies this 2D simulation. This implementation cannot be seen as an ultimate objective, but it is a required step to (a) implement a baroclinic 3D model (it will be nested into this one to get the tide) and (2) to assess the contribution of each forcing effect for the actual flow between and around the islands.

The tide along the open boundary of this implementation was obtained from the model FES2014, which also provides levels inside the modelling domain. Our results do not add much to the levels already provided by FES2014 as the two submodels nested into our main model do not provide heather. The difference between the results of these models are the currents, that are in fact the major contribution for users, whatever they are managers or scientists from other disciplines.

2. The Study Area

The Cape Verde archipelago (Figure 1) is located in the Atlantic Ocean on the subtropical region, west of the African coast, between 17º12'15''N and 14º48'00''N and 22º39´´20''W and 25º20'00''W. The archipelago includes ten major islands, nine of which inhabited, and several uninhabited islets, divided in two groups (Figure 1): at north, the Windward Islands ("Ilhas do Barlavento"), and the Leeward Islands ("Ilhas do Sotavento") at the south. The Windward Islands include

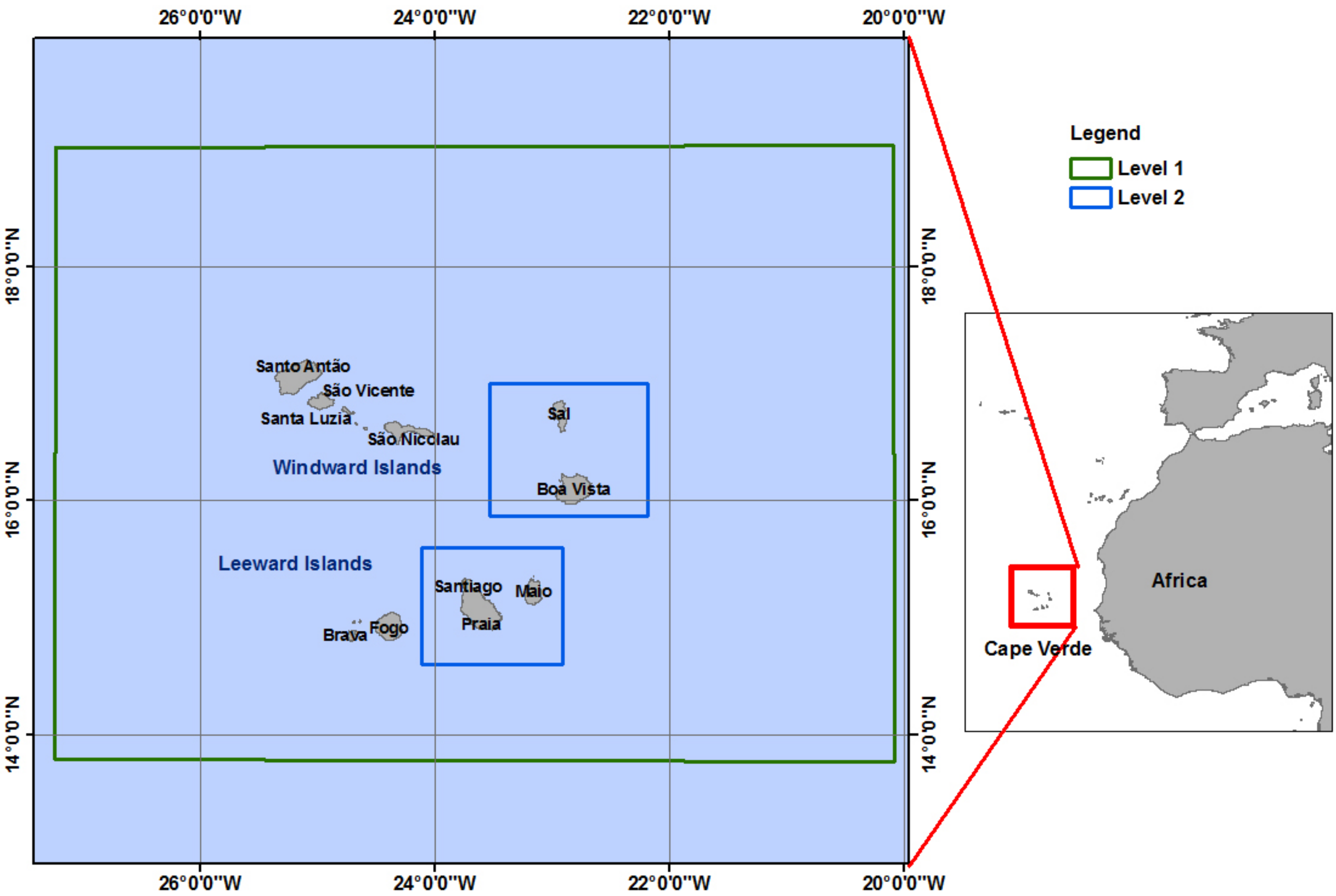

Figure 1 - Geographical location of the archipelago of Cape Verde, Windward and Leeward island groups. The domain of simulation of the Level 1 model is the green rectangle. Blue rectangles identify the regions simulated by nested models.

Figura 1 – Localização geográfica do Arquipélago de Cabo Verde e dos grupos de ilhas de Barlavento e de Sotavento. O rectângulo verde mostra a domínio simulado com o modelo nível 1 e os rectângulos azuis os domínios dos modelos encaixados.

the islands of Santo Antão, São Vicente, Santa Luzia (uninhabited island), São Nicolau, Sal and Boavista. The Leeward Islands include the islands of Maio, Santiago, Fogo and Brava. The archipelago has volcanic origin, with rugged and arid terrain and little vegetation. Most of the islands are mountainous, except the island of Sal, Boavista and Maio, which are flat with long beaches.Weather conditions in the region of Cape Verde are characterized by prevailing northeast trade winds occurring throughout the year. These winds influence intensity and direction of surface currents as well as the sea level height. Higher wind intensities are more frequent in the Leeward Islands than in the Windward Islands (DGA, 2004).

3. Material and methods

In the study region the data available is scarce and all the information available was used in the present study. We have used the bathymetry from NASA SRTM (Shuttle Radar Topography Mission) database with spatial resolution of 30 seconds, the tidal data from a station located at Palmeira harbor (Sal Island) and wind velocities measured at a meteorological station located nearby the same harbor. Also the tidal data from the global model FES2004 and the wind fields from GFS model were used. The numerical model used to perform the simulations is the MOHID water modelling system.

Tide data measured in Palmeira harbour (Figure 2), Sal Island are available in the British Oceanographic Data Center (www.bodc.ac.uk). The most recent information dates back to 2000 and the time series covers 8 months (07-04-2000 to 31-12-2000). This data was processed to extract the main tidal components. Table 1 shows amplitude and phase of the most significant tidal components extracted using the T_tide software (Pawlowicz *et al.*, 2002): principal lunar (M_2), principal solar (S_2), lunar elliptic (N_2), luni-solar diurnal (K_1), principal lunar diurnal (O_1), luni-solar (K_2), solar semi-annual (Ssa), principal solar diurnal (P_1), lunar fortnightly (Mf), quarter-diurnal (M_4) and lunar monthly (Mm).

Model implementation was challenged by the lack of data and the absence of previous modeling studies at the scale of the archipelago. Two nested modelling levels were used: the level 1 with a coarser grid (green rectangle in Figure 1) uses a 6 km resolution and covers a domain of about 480 000 km^2; The level 2 with finer

Table 1 - Frequency, amplitude and phase of the main tidal components at Palmeira harbour (Sal Island).

Tabela 1 - Frequência, amplitude e a fase das principais componentes da maré no Porto Palmeira (Ilha do Sal).

Tidal component	Frequency (h^{-1})	Amplitude (m)	Phase (°)
M_2	0.080511	0.296	276.69
S_2	0.083333	0.116	317.22
N_2	0.078999	0.058	249.59
K_1	0.041781	0.052	351.32
O_1	0.038731	0.042	260.03
K_2	0.083562	0.034	312.11
Ssa	0.000228	0.028	20.39
P_1	0.041553	0.016	337.65
Mf	0.00305	0.015	19.28
M_4	0.161023	0.014	286.94
Mm	0.001512	0.012	346.42
NU_2	0.079202	0.012	247.09

grids (blue rectangles in Figure 1) uses a 3 km resolution and cover two areas one of the order of 25 000 km^2 for the region of the Sal and Boavista Island and another of order of 17 000 km^2 for the region of Santiago and Maio Island.

Tides were imposed at the open boundary of Level 1 using results from the global tide model FES2004 (Lyard *et al.*, 2006). The two nested models use the levels and velocities computed by Level 1 to specify initial and boundary condition values. Atmospheric forcing was imposed on both modelling levels using GFS model (Center, 2003) results. The inverted barometer method was used to specify the atmospheric pressure at Level 1. A relaxation condition with an exponential decay over ten cells was used to avoid reflections at the border between the nested models and the Level 1 model. The simulation was performed for a period of two months between April and May 2000. A model spin-up of one month was considered and the model results analyses is performed only for the month of May.

Figure 2 shows the bathymetry of the Level 1 model showing the underwater connection between groups of islands and the vicinity of deep ocean depths between islands. The location of the Palmeira harbour (green point), the fixed buoy (blue point, latitude 16° 45' 22" N, longitude 23° 3' 47" W) where water level data was collected and the weather station where the wind observations were obtained (latitude 16° 43’ 48’’ N, longitude 22° 57’ 3’’ W, height 54 m [www.tutiempo.net]) are also shown in Figure2.

Figures 3 compares the water level reconstructed using the tidal harmonics obtained from the Palmeira Port buoy data (dots) with the water level extract from the FES2004 model (line) for a point with the same location of the buoy for the May month. The analysis shows globally a good agreement between the two time series, although in some days differences of the order of 10 cm can be observed. The correlation coefficient between the two series is 94.48% (Figure 4) showing that a tidal model forced by the FES2004 results is also expected to have good results.

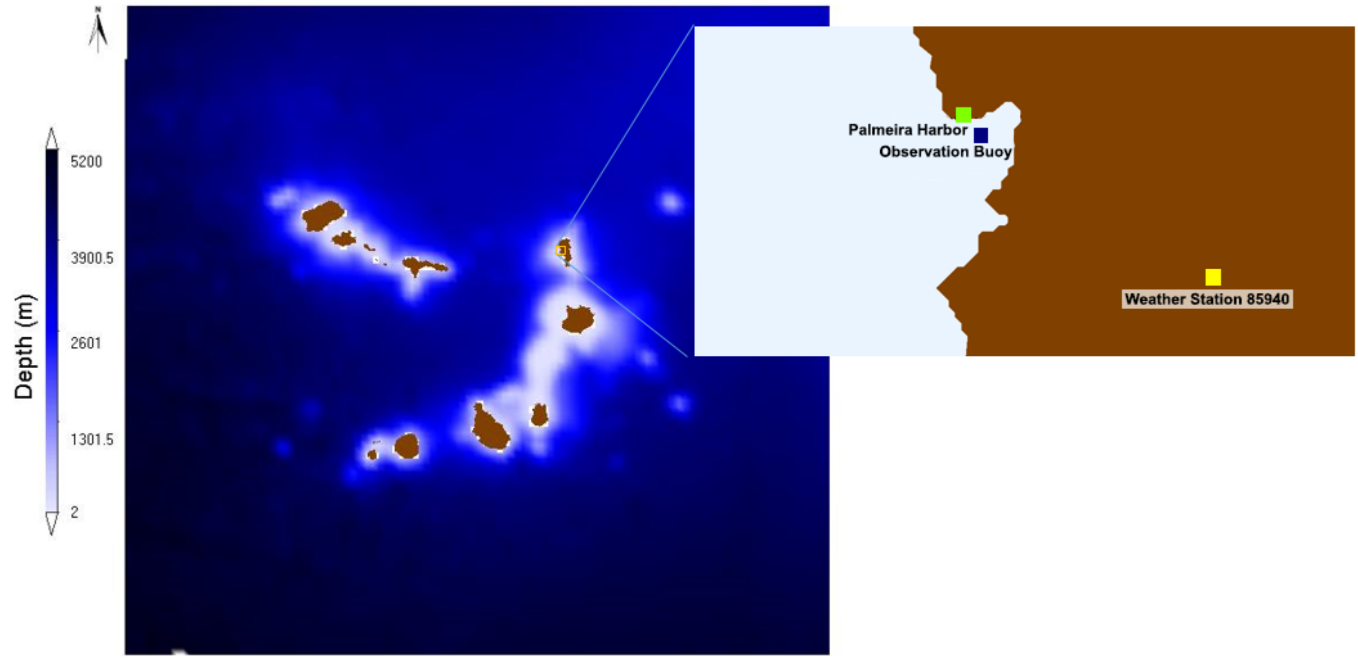

Figure 2 - Bathymetry of the archipelago of Cape Verde and location of the Palmeira Harbour (green dot), of the observation buoy (blue dot), and of the inlan meteorological station (yellow dot).

Figura 2 - Batimetria do arquipélago de Cabo Verde e localização do porto da Palmeira (ponto verde), da bóia de observação (ponto azul) e da estação meteorológica (ponto amarelo) localizada em terra.

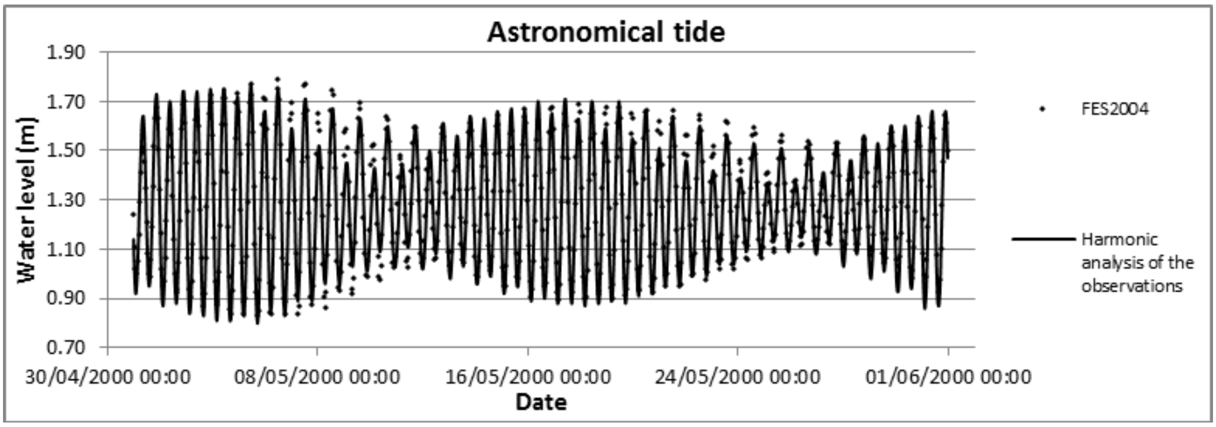

Figure 3 – Comparison of levels reconstitute from FES2004 model (line) harmonics and from harmonics measured at Palmeira harbour.

Figura 3 - Resultados do nível da maré astronômica das componentes da maré do modelo FES2004 (linha) e da análise harmônica das observações (ponto), Porto da Palmeira, Maio de 2000.

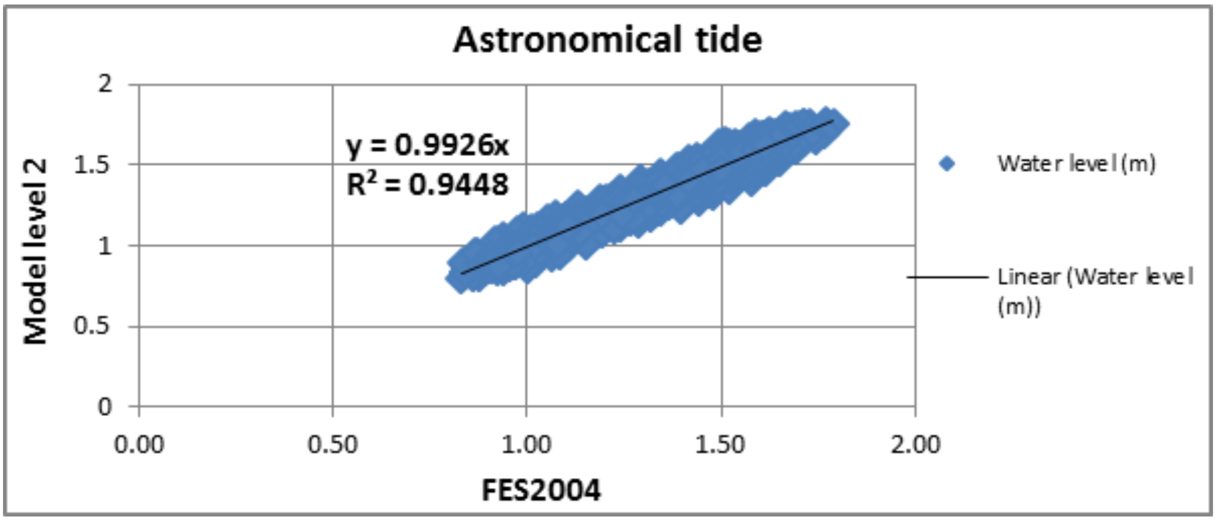

Figure 4 - Correlation between the astronomical tide data and the FES2004, Palm harbour, May 2000.

Figura 4 - Correlação entre a maré astronómica dos dados e o FES2004, para a estação do Porto da Palmeira, Maio de 2000.

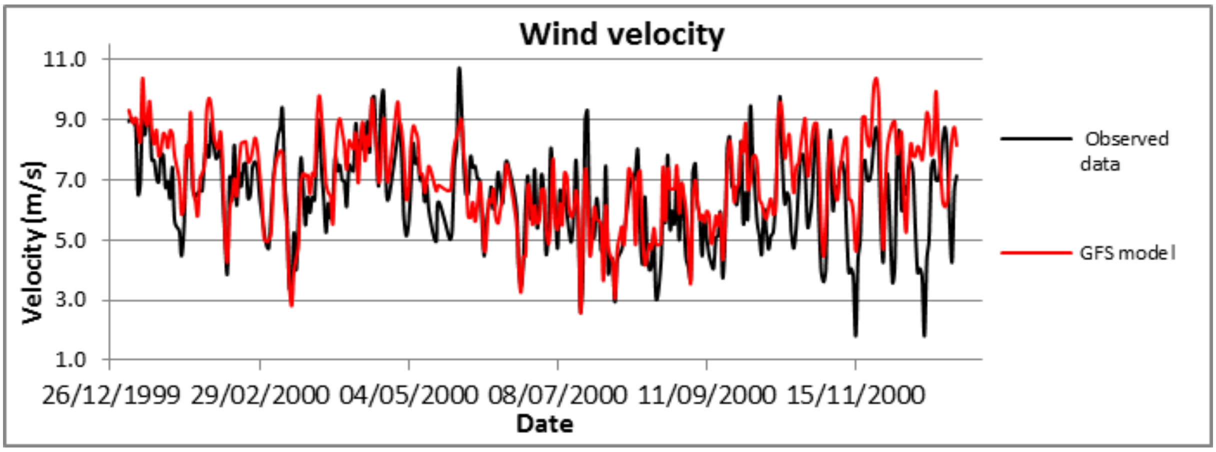

Figure 5 – Time series of daily mean wind velocity, over the 2000 data and GFS weather model at a point on the island of Sal, Cape Verde.

Figura 5 – Séria temporal da velocidade média diária do vento, ao longo do ano 2000, dos dados e do modelo meteorológico GFS num ponto na ilha do Sal, Cabo Verde.

Wind from GFS model was assessed using the data from the meteorological station located at Sal Island, in the vicinity of the Palmeira harbour (Figure 2). Figure 5 compares time series for the year 2000 showing that the model meteorological captures the main features of the field data and consequently can be used to specify the surface wind stress. The data shows typical wind velocities of the order of 7 m/s, with higher values in autumn and spring - when velocities often reach 9 m/s - and lower velocities in summer. The agreement between measured and modelled winds show that GFS model can be used to spec the surface wind fields to the hydrodynamic model.

3.1. MOHID water modelling system

MOHID is an open source water modelling system (Neves, 2013) which development is centred at the Instituto Superior Técnico (IST), Universidade de Lisboa, Portugal. It is a modular system based on finite-volumes able to use Cartesian or Sigma vertical grids or a combination of both, including vertical movement of the grid to minimise numerical diffusion associated to internal waves. In this application only one sigma layer is used and consequently the simulation is a 2D vertically integrated. The versatility of the modular structure allows the model to be used in virtually any free surface flow. It was applied in most Portuguese estuaries to simulate hydrodynamics and water quality (Saraiva *et al.*, 2007; Lopes *et al.*, 2009; Malhadas *et al.*, 2010; Kenov *et al,* 2012) and in regional seas (Martins *et al.*, 2001). Other applications of MOHID include Galician estuaries such as Ría de Vigo (Taboada et al., 1998; Gomez-Gesteira et al., 1999), and Ría de Pontevedra (Ruiz-Villarreal *et al.*, 2002). Recently, MOHID has been applied to the coast of Southern America (Campuzano *et al.*, 2013). The model software is written in ANSI FORTRAN 95, following object-oriented programming. MOHID includes a graphic user interface with tools for data handling, pre-processing, simulation's management, and post-processing. MOHID uses a semi-implicit algorithm allowing the simulation of complex problems in small computers and can perform parallel computing using openMP or MPI technologies. 3D baroclinic models can be nested into 2D models in order to get the tide at the boundaries. This will be a major use of the 2D tidal model described in this paper which solves the set of equations:

$$\frac{\partial \eta}{\partial t} + \left[\frac{\partial}{\partial x}(uD) + \frac{\partial}{\partial y}(vD)\right] = 0 \quad \text{Equation 1}$$

$$\frac{\partial}{\partial t}(uD) + \left[\frac{\partial}{\partial x}\left(u^2 D\right) + \frac{\partial}{\partial y}(uvD)\right] - fvD = = -gD\frac{\partial \eta}{\partial x} + \frac{1}{\rho}\tau^x + D\left[\frac{\partial}{\partial x}\left(A\frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(A\frac{\partial u}{\partial y}\right)\right] \quad \text{Equation 2a}$$

$$\frac{\partial}{\partial t}(vD) + \left[\frac{\partial}{\partial x}(uvD) + \frac{\partial}{\partial y}\left(v^2 D\right)\right] - fuD = = -gD\frac{\partial \eta}{\partial y} + \frac{1}{\rho}\tau^y + D\left[\frac{\partial}{\partial x}\left(A\frac{\partial v}{\partial x}\right) + \frac{\partial}{\partial y}\left(A\frac{\partial v}{\partial y}\right)\right] \quad \text{Equation 2b}$$

where u and v are the velocity components along the x and y directions; f is the Coriolis parameter, a function of the latitude; A is the coefficient of horizontal viscosity; τ^x and τ^y are the wind stresses along the x and the y directions, respectively; D is the total water column height calculated as $D=h+\eta$, where h is its depth below the reference level and η is the elevation above that level (Kantha and Clayson, 2000).

4. Analysis and discussion of results

This section starts with the validation of water level using the Palmeira harbour data and describes and discusses the results of the Level 1 model (coarser grid) and Level 2 model (finer grid). Figure 6 shows the comparison between water level observations reconstitute using the harmonic components and the results of the Level 1 model. Both series show identical evolutions, the differences being comparable with the differences between comparable with differences between FES2004 results used to force the model and the observations shown in Figure 3. This agreement proves that the model is propagating the tide correctly in the Level 1. Figure 7 shows the correlation between simulated and observed free surface level time series at Palmeira harbour, shown in Figure 6. The correlation coefficient is 95.68%, slightly higher than the correlation between data and FES2004 results. Figure 8 shows the same comparison for the Level 2 results. The differences are identical and consequently the correlation coefficient is also similar (95.39%) showing that to obtain correct water levels is not necessary to have a very high resolution model. High resolution models are in fact required to compute high resolution velocity fields, where topographic features can generate strong velocity gradients with implications on vertical transport of nutrients and chlorophyll production.

4.1. Spatial analysis of the main tidal constituents

The time series analysis at the Palmeira harbour has shown that the FES2004 is good enough to specify the tide at the model boundaries and that MOHID is good enough to simulate the tidal propagation within the modelling domain and its results can be used to describe the tidal propagation. In this chapter the spatial analysis of the main tidal components (M_2, S_2 and N_2) will be performed using the model results. Figures 10 to 12 display maps of amplitudes and phases.

Results show that the three semi-diurnal tidal components (M_2, S_2 and N_2) propagate northward and that the islands play a major role on the propagation of

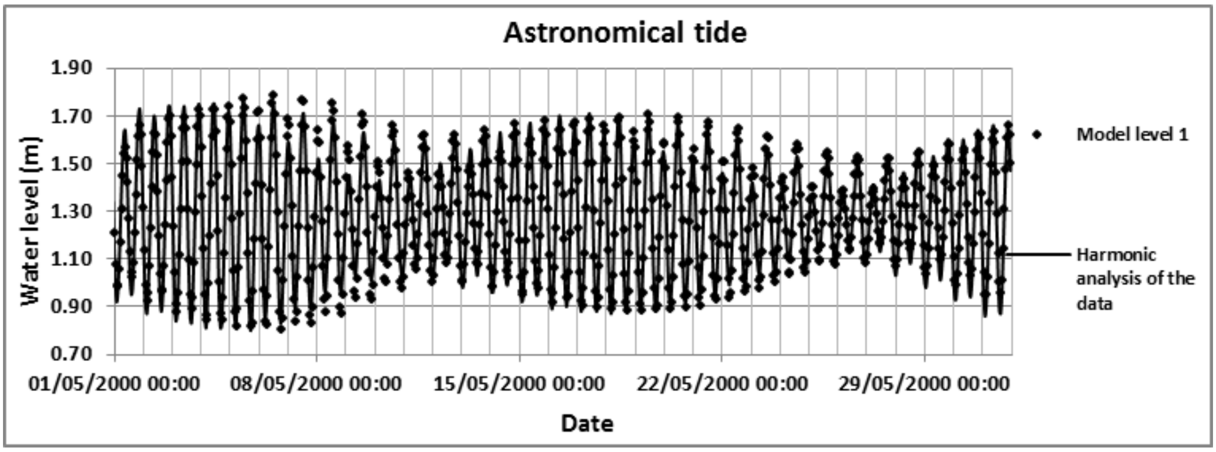

Figure 6 - Results of the tidal model - level 1- and levels reconstitute from observation's harmonics (line) at Palm harbour.

Figura 6 – Resultados do modelo de maré - nível 1 – e níveis reconstituídos (linha) a partir das componentes harmónicas medidas no Porto da Palmeira.

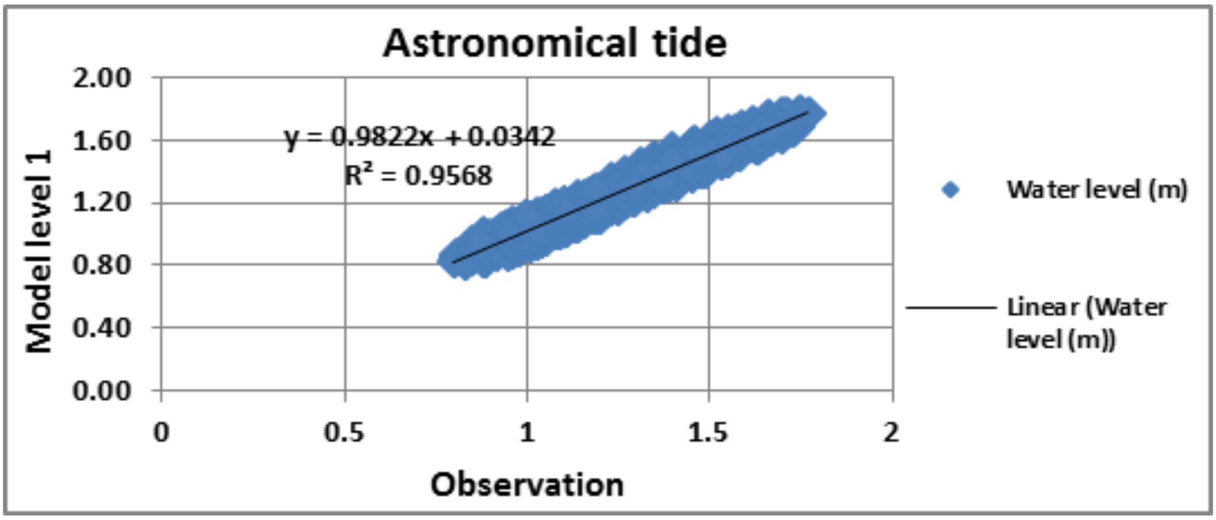

Figure 7 - Correlation between results of the tidal model - level 1 - and levels reconstitute from observation's harmonics at Palmeira harbour.

Figura 7 – Correlação entre resultados do modelo de maré - nível 1 – e níveis reconstituídos a partir das componentes harmónicas observadas em Porto da Palmeira.

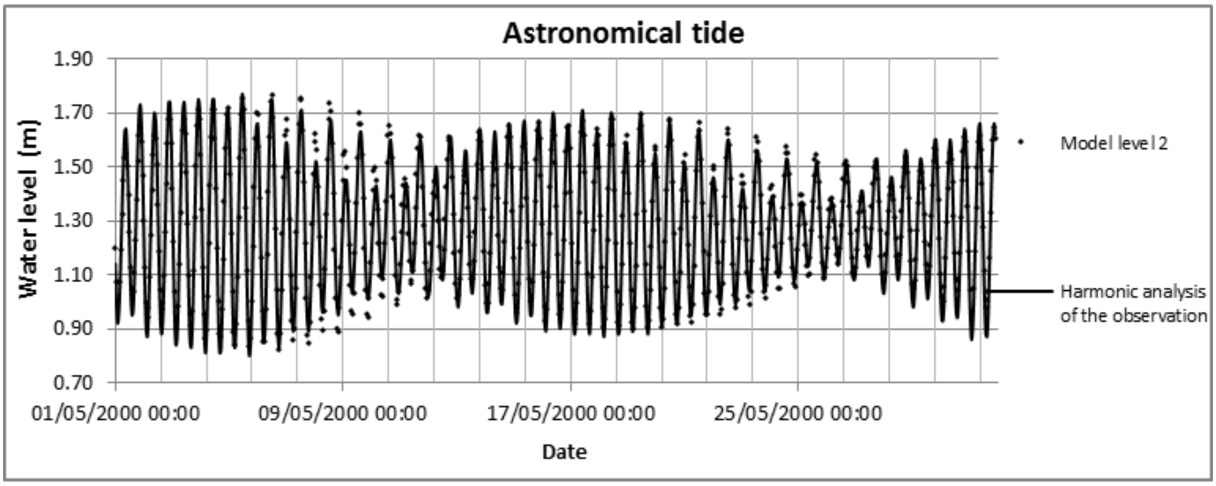

Figure 8 - Results of the tidal model - level 2- and levels reconstitute from observation's harmonics (line) at Palm harbour.

Figura 8 - Resultados do modelo de maré - nível 2 – e níveis reconstituídos (linha) a partir das componentes harmónicas medidas no Porto da Palmeira.

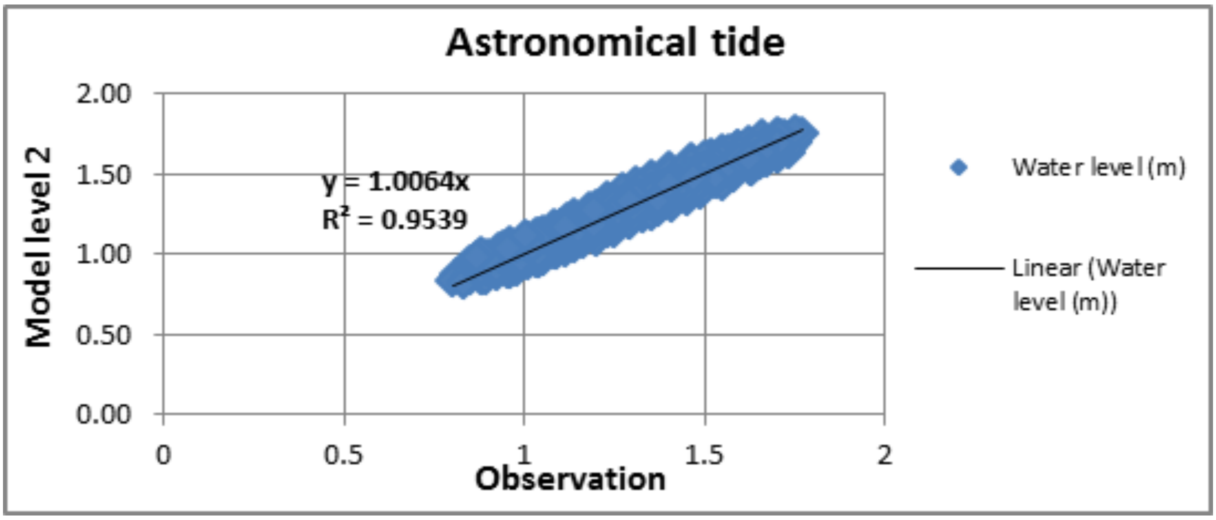

Figure 9 - Correlation between results of the tidal model - level 2 - and levels reconstitute from observation's harmonics at Palmeira harbour.

Figura 9 - Correlação entre níveis calcula pelo modelo de maré - nível 2 – e a partir das componentes harmónicas observadas em Porto da Palmeira.

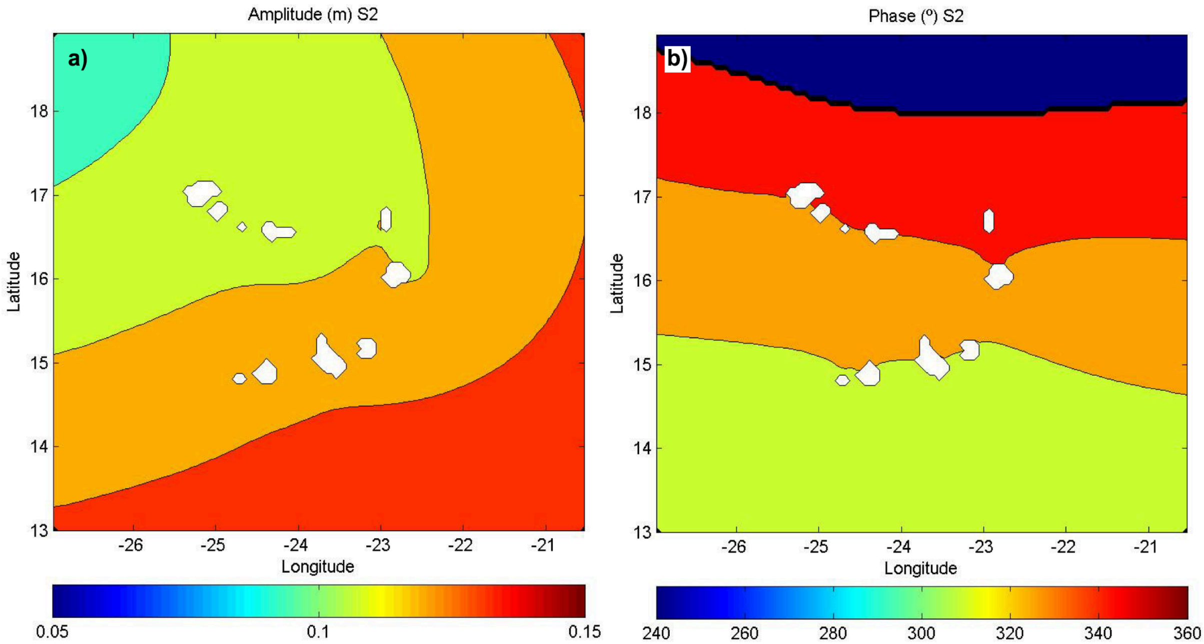

Figure 10 – Maps of co-tidal (a) and co-phase (b) in Cape Verde for M_2 constituent.

Figura 10 – Mapas de co-corrente (a) e co-fas (b) Cabo Verde para a componente M_2.

these components, distorting the isolines and creating regions of higher gradient and thus regions of increased velocity. The M_2 amplitude varies between 0.4 along the southern boundary to about 0.24 m at the northern, while the phase increases from 270° to 310°. In general, the amplitude of the N2 and S2 tidal component show an increase from north to south, in agreement with literature (Lyiard et al., 2006). The N2 and S2 components show little variations in amplitude, ranging between 0.1 and 0.15 m for S2, and between 0.05 and 0.1 for N2. Changes in amplitude are observed in transition zones where morphology and depth variations occur due to the presence of the islands.

4.2. Tidal Circulation

Figure 13 shows in two situations of maximum flood and ebb current on the 20^{th} May 2000. The figure shows that the tidal flow is globally oriented north-south and that the islands behave as barriers to the flow inducing higher velocities in the channels between the islands and on the extremes of the island groups. Maximum velocities of the order of 30 cm/s are computed in the channels between the islands.

Out of the island barrier effect the flow displays low velocity, of the order of 5 cm/s. This flow pattern shows that the islands play an important role on the local cir

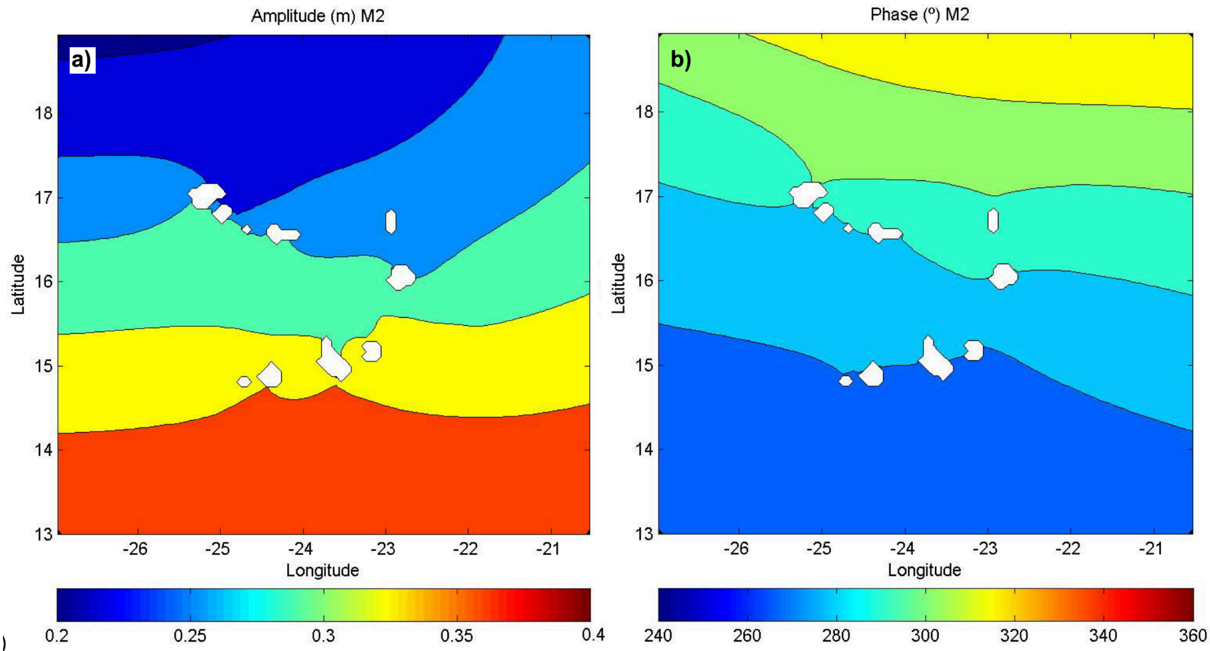

Figure 11 – Maps of co-tidal (a) and co-phase (b) in Cape Verde for S_2 constituent.

Figura 11 – Mapas de co-corrente (a) e co-fase (b) em Cabo Verde para a componente S_2.

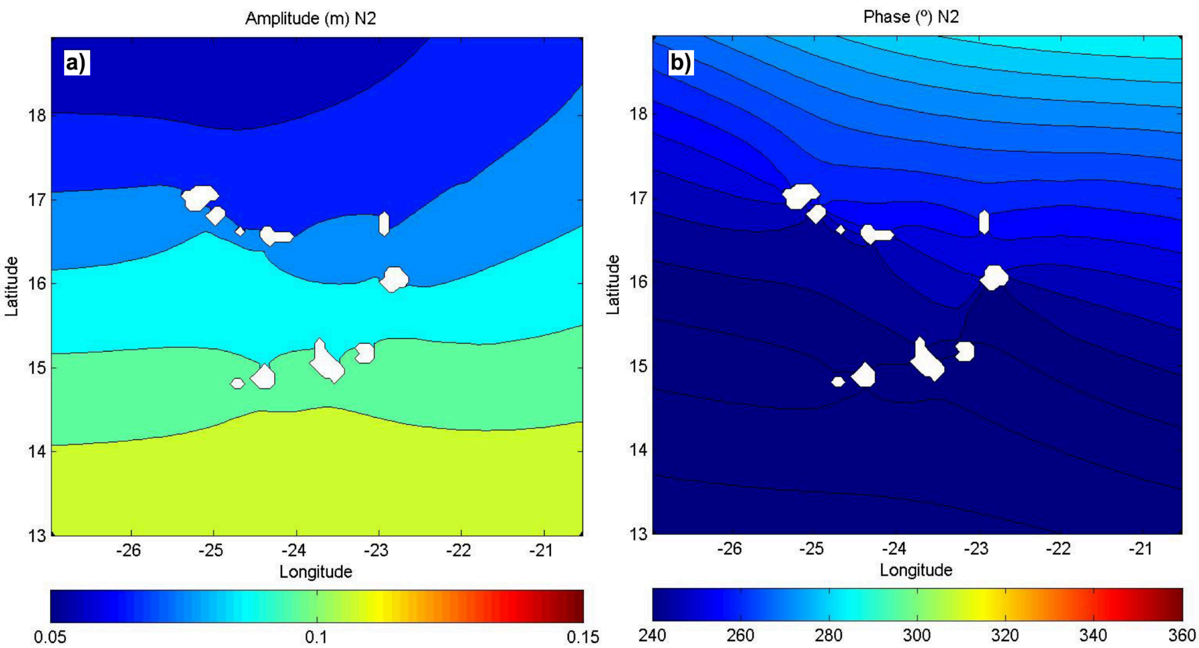

Figure 12 – Maps of co-tidal (a) and co-phase (b) in Cape Verde for N_2 constituent.

Figura 12 – Mapas de co-corrente (a) e co-fase (b) em Cabo Verde para a componente N_2.

culation and that close to the coast the tide must be considered in any circulation study. The strong acceleration of the flow registered in the vicinity of the islands induces important non-linear effects and strongly increases the local importance of the Coriolis force. As a consequence strong residual currents have to be expected with a tendency for anticyclonic rotation due to Coriolis.

4.3. Residual Circulation

The residual velocity is the average of the transient velocity at each point and accounts for the non-linear effects, resulting from the advective and the friction terms. The Coriolis term in presence of a solid boundary also generates residual flow. In deep ocean advection and friction are of secondary importance and

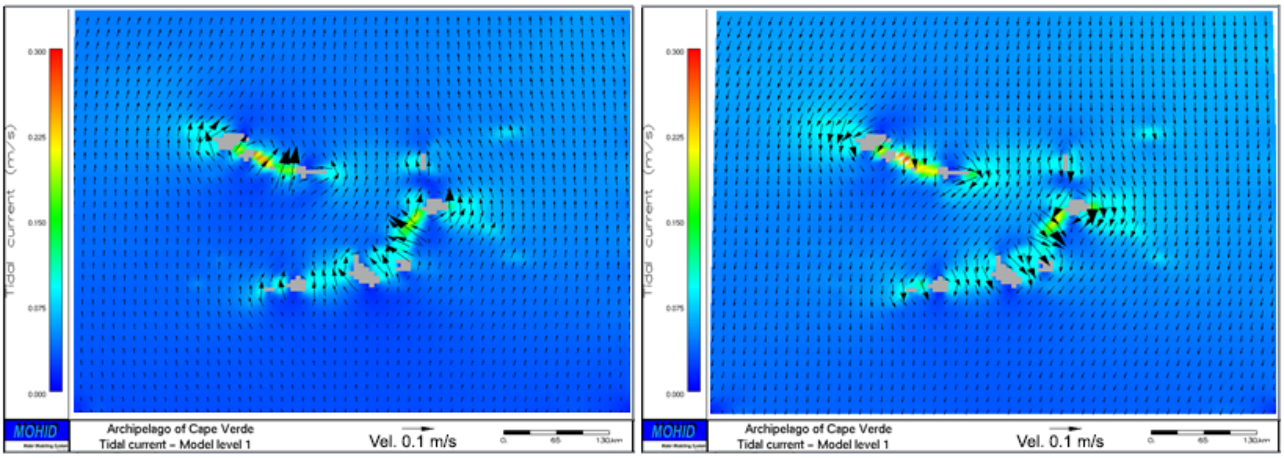

Figure 13 - Tidal currents in the archipelago of Cape Verde (maximum velocity 0.3 m/s) during ebb and flooding (20th May 2000).

Figura 13 – Correntes da maré no arquipélago de Cabo Verde (Máximo da escala 0.3 m/s) em enchente e vazante no dia 20 de Maio de 2000.

consequently residual velocities are very weak. However around islands all non-linear terms get more important.

The advective terms tend to generate eddies in the back side of island, when the water leaves the island. These eddies even if not present in the transient flow, tend to exist in the residual flow since the inertia force is not present when the flow approaches the island. As a consequence around an island in an oscillating tidal flow advection and friction promote the presence of eddies, two on each side of the island. This effect was illustrated by Pingree and Maddock (1980). In presence of earth rotation the Coriolis generates a rotation (anticyclonic in the northern hemisphere) around the island that modulates the four - eddies flow, increasing the residual velocity in two eddies diametrically opposed and decreasing them in the intermediate eddies. The presence of this rotational flow was already pointed out by Huthnance (1973).

Figure 14 shows the residual flow computed by the Level 1 model and displays the tendency for the anti-cyclonic flow around the islands or groups of islands. This flow is particularly clear around the Windward Islands on the northwest, showing that the Coriolis Effect is the major mechanism generating residual flow. In the same group is also clear the presence of higher velocities in the northwest and southeast corners suggesting that the advective and friction terms are also contributing for the residual flow. The most southern islands present a more complex residual flow pattern which is a consequence of a more complex tidal flow.

The residual flow represents the tendency of the transport. Its knowledge is important to foresee the displacement of pollutants discharged from permanent sources or to understand the sediment transport in regions deep enough to be independent of the wave transport. However the effective transport requires the use of transient models forced by actual wind.

Independently of the practical importance of the residual circulation for coastal management support, this analysis of the residual circulation was an important contribution to validate the model results and thus to increase confidence on the model as a tool to generate knowledge about the hydrodynamic circulation in the Cape Verde Archipelago.

4.4. Effect of meteorological conditions on currents and water level

Qualitative and quantitative assessment of the effect of Qualitative and quantitative assessment of the effect of the meteorological conditions were performed by considering scenarios with and without atmospheric forcing. The wind was imposed both in the in the large and local scale models and the differences between the two scenarios were assessed on level 2 model results where shallow areas are. Figure 15 shows a wind velocity fields and pressure distributions (in color) for the 20th May 2000 at 12pm. The figure shows northern winds decreasing southwards with a maximum speed of the order of 11 m/s and the atmospheric pressure decreasing from Northwest to Southeast. These wind patterns are identified in the "*Livro Branco sobre o Estado do Ambiente em Cabo Verde*" as a typical wind field the wind intensity is also identified as being typical in the site http://www.tutiempo.net/clima/Sal/04-2000/85940.htm.

Figure 16 compares time series of levels computed with and without wind forcing. The comparison shows that at this location wind forcing generates differences of the order of centimeters. Instantaneous spatial distributions of levels are shown in Figures 17 (a) and 18 (a). These figures show differences of the order of 3 cm,

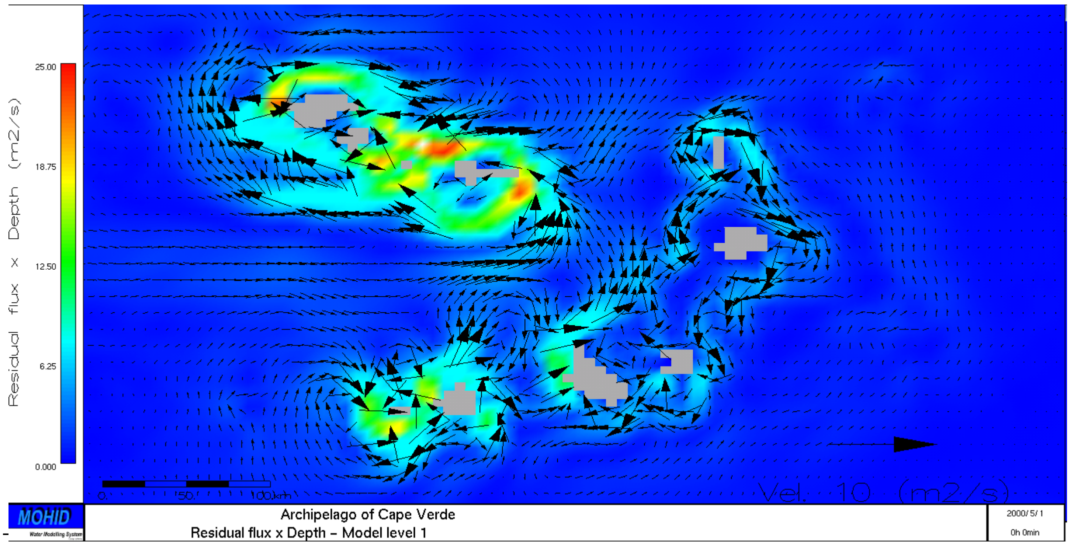

Figure 14 - Residual Flux in level 1 model. It is clear the tendency for an anticyclonic circulation around the islands.

Figura 14 – Velocidade residual no modelo de nível 1. É clara a tendência para a existência de um escoamento anticiclónico em torno das ilhas.

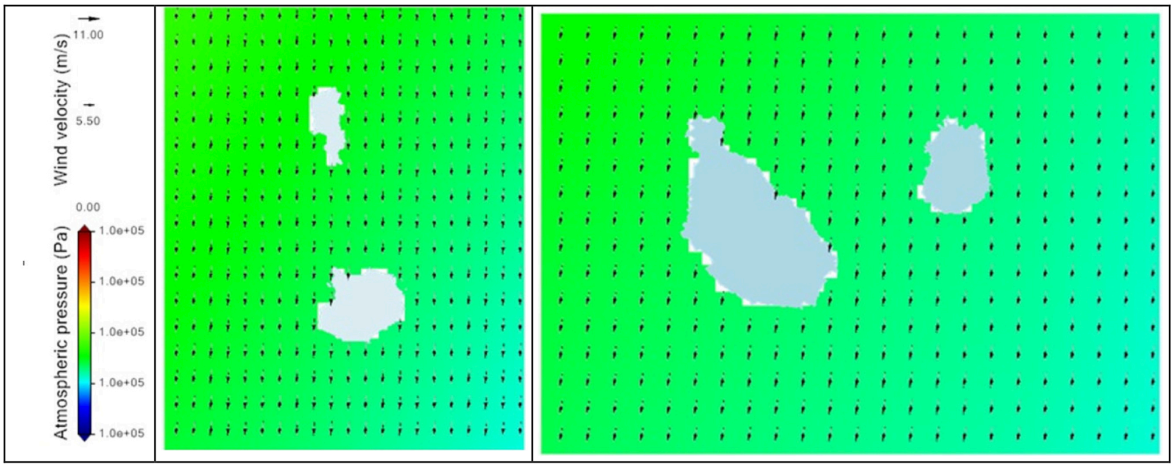

Figure 15 - Results of the tide elevation with (dots) and without (line) meteorological forcing, Palmeira harbour, May 2000.

Figura 16 - Resultados da elevação da maré com (pontos) e sem (linha) forçamento meteorológico, Porto da Palmeira, May de 2000.

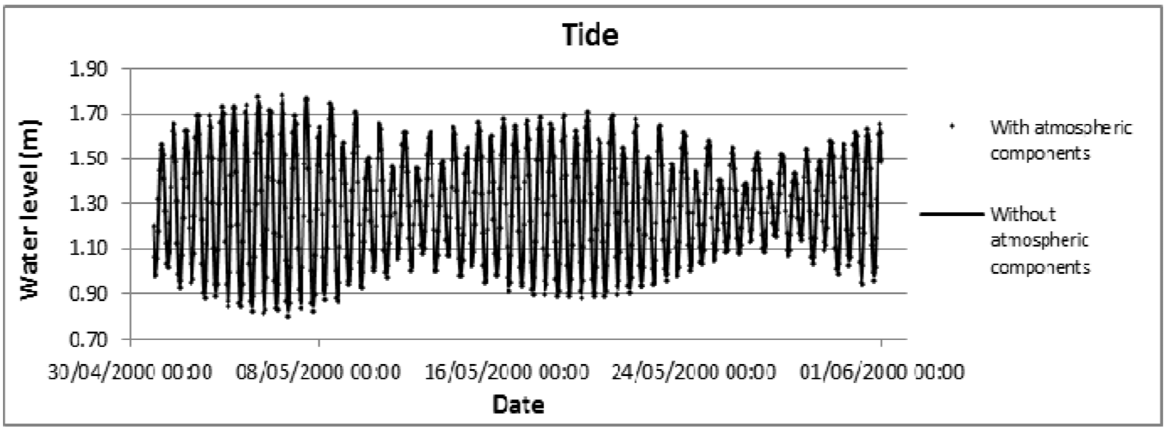

Figure 16 - Results of the tide elevation with (dots) and without (line) meteorological forcing, Palmeira harbour, May 2000.

Figura 16 - Resultados da elevação da maré com (pontos) e sem (linha) forçamento meteorológico, Porto da Palmeira, May de 2000.

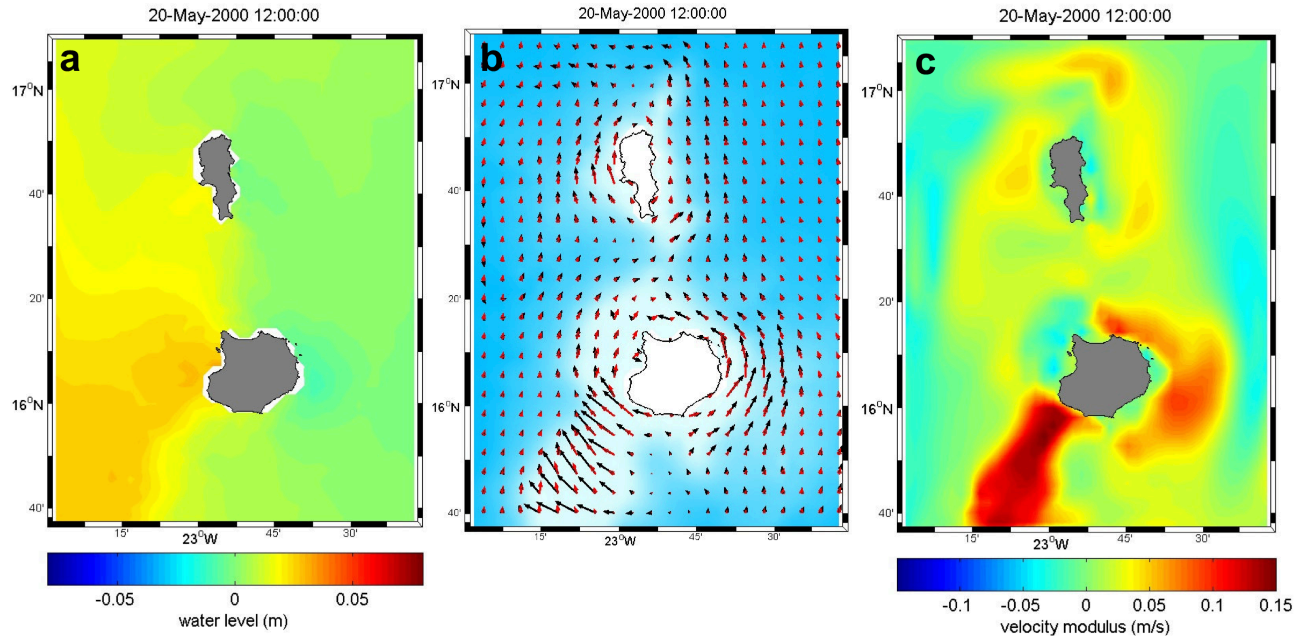

Figure 17 – Comparison of solutions with and without wind forcing in the region of Sal and Boavista islands for the 20 of May 2000 at 12pm: (a) level difference, (b) Velocity vectors (black with and red vector without the atmospheric forcing); (c) velocity intensity difference.

Figura 17 – Comparação da solução com e sem forçamento atmosférico na região da ilha do Sal e Boavista no dia 20 de Maio de 2000 às 12h: (a) diferença de níveis (b) vectores velocidade (preto com e vermelho sem forçamento atmosférico); (c) diferença do módulo da velocidade.

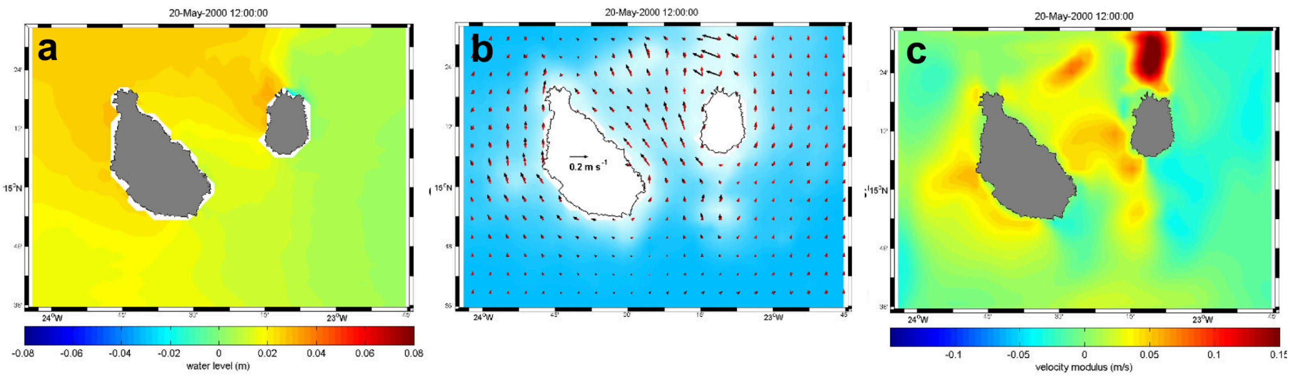

Figure 18 Comparison of solutions with and without wind forcing in the region of Maio and Santiago islands for the 20 of May 2000 at 12pm: (a) level difference, (b) Velocity vectors (black with and red vector without the atmospheric forcing); (c) velocity intensity difference.

Figura 18 - Comparação da solução com e sem forçamento atmosférico na região das ilhas de Maio e de Santiago Boavista no dia 20 de Maio de 2000 às 12h: (a) diferença de níveis (b) vectores velocidade (preto com e vermelho sem forçamento atmosférico); (c) diferença do módulo da velocidade.

for the 20th May at 12pm. High values are located northwest which is consistent with the northeast wind forcing.

The comparison of the velocity field for the scenarios with and without meteorological conditions is presented in Figures 17 (b) and 18 (b). The black arrows represent velocity with meteorological forcing and the red arrows represent velocity without meteorological forcing. The results show that there is a significant difference in the intensity and direction of the currents in the two scenarios over the shallow areas. This effect is enhanced near the coast, as expected, due to the higher effect of wind in shallow areas over the whole water column. The current intensity tend to increase perpendicularly to the wind which is attributed to the Coriolis effect. The maximum current velocity difference between the two scenarios is about 0.15 m/s, in the shallow regions. In the deeper regions differences are small. However they are expected to be of the same order of magnitude if a 3D baroclinic model was used.

Globally results show that meteorological forcing is a major mechanism generating velocity in the region. Associated to vertical density stratification its importance it is expected to be even higher since it will be responsible for upwelling and downwelling events around the islands with important biogeochemical consequences.

5. Conclusions

This study represents a first step towards a more comprehensive understanding of tidal circulation in the Cape Verde region. The study used all the data available locally and made available by large scale initiatives to study the global ocean and atmosphere dynamics. In the absence of field data model, verification of model results was supported by the agreement with known physical processes. Particularly important was the residual flow pattern around the islands and groups of islands and the modification of the flow pattern by the wind.

The water level observations from the buoy located at Palmeira harbor, dating back to the year 2000 were the only source of data available for quantitative assessment of the water levels computed by the model. These data allowed for the characterization of the major tidal constituents which were very useful to assess the realism of the FES2004 model results to impose the boundary conditions, but also to validate the MOHID model results generated both by the coarser and finer resolution models, with correlations of 95.68% and 95.39% respectively. These comparisons show that the fine resolution model was irrelevant to compute tidal levels. Fine resolution model is however important to compute velocities since results of the model show that tidal currents next to the islands are determined by the archipelago morphology, being maxima in the channels between the islands, as expected.

Meteorological forcing has shown to be very important for the flow in regions where the flow is confined to the surface layer, that in a 2D depth integrated model can happen only in the shallow regions around and between the islands, where wind driven currents can be more important than the tidal currents. This means that in stratified regions where the wind effect is confined to the surface by buoyancy wind circulation is very important and thus the next step of this work must be based on a 3D baroclinic model.

This work is an important step for the understanding of the general characteristics of the tidal currents in the archipelago of Cape Verde that is necessary step for the understanding of the relative importance of each process responsible for the flow in more comprehensive hydrodynamic studies.

The residual flow pattern is already very important to support the management of anthropogenic discharges, and globally the results are of great importance to design the field experiments that must precede any water quality study or to support spatial planning and tourism development in Cape Verde.

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Benefit maximizing criteria from the Nigerian Coastal and Inland Shipping Cabotage Policy[*]

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ABSTRACT

This paper reviews government policies of developing maritime nations affecting investments in ship sizes operating in lakes, rivers canals, Inland waters and coastal waters of these maritime states. The Nigerian cabotage policy was specially reviewed in this work, picking out loopholes and areas of possible co-operation with ship investment organizations from the developed maritime nations. Opportunities in the West African nation's transportation network were identified from a careful study of the nation's internal water network, rich mineral deposits, oil and gas reservoirs, emerging coastal cities and hinterland commercial nerve centre. Strategic investment options for the global investor shipping firms with other African countries which use the cabotage were identified in the cabotage policy framework. Applied analytical models include benefit/cost analysis, real – options investment analysis, SWOT analysis welfare analysis of MARPOL compliant river crafts. Vessel types for which analysis were carried out include passenger vessels, bunkering vessels, fishing trawlers, barges, tugs dredgers, tankers (coast wise) marine mining vessels, waste disposal vessels, carriers (short sea non cargo vessels), and lighters.Identified strategic management options include the merger option, strategic alliances, joint venture strategies.

The experience of the foreign ship operator in the region was identified as a major advantage in the globalization of the river, and coastal size vessel operating companies. The implications of their participation in the Nigerian cabotage policy were also highlighted. Emerging areas in the cabotage rule in world affairs were also identified.

Keywords: Exclusive Economic Zone; Cargo Protection; SWOT Analysis; Joint Ventures; Offshore Support Vessels.

RESUMO

Critérios de maximização de benefícios da política nigeriana de cabotagem.

Este trabalho revisa as políticas governamentais de desenvolvimento de nações marítimas que afetam os investimentos na dimensão de navios que operam em lagos, canais fluviais, águas interiores e águas costeiras desses estados marítimos. É especialmente focada a política de cabotagem nigeriana, identificando lacunas e áreas de possível cooperação com as organizações investidoras das nações marítimas mais desenvolvidas.Foram identificadas oportunidades nas redes de transportes dos países oeste-africanos a partir de um estudo cuidadoso das redes aquaviárias, dos depósitos minerais mais importantes, dos reservatórios de petróleo e gás, e das cidades litorâneas e do interior que constituem centros comerciais nevrálgicos. No quadro da política de cabotagem foram identificadas opções estratégicas de investimento para as empresas globais de navegação. Os modelos analíticos aplicados incluem análise de custos / benefícios, análise de investimentos, análise SWOT de bem-estar, análise da MARPOL compatíveis com embarcações fluviais. Os tipos de navios considerados incluem navios de passageiros, navios de abastecimento, traineiras de pesca, barcaças, rebocadores, dragas, navios-tanque, navios mineraleiros marinhos, navios de eliminação de resíduos, navios transportadores (de curta distância, não de carga) e navios ligeiros. As opções estratégicas de gestão identificadas incluem a fusão, alianças estratégicas, empreendimentos conjuntos (joint venture).

A experiência de operadores navais estrangeiros na região foi identificada como muito positiva na globalização do rio, e para as empresas de exploração de embarcações costeiras. Foram também destacadas as implicações de sua participação na política de cabotagem nigeriana, bem como as áreas emergentes de cabotagem no panorama dos negócios mundiais.

Palavras-chave: *Zona Económica Exclusiva; Proteção de Carga; Análise SWOT; Joint Ventures; Embarcações de apoio offshore.*

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1. Introduction

Marine policy formulation is often viewed by developing maritime states as the key instrument to achieving ownership sufficiency in the carriage of a reasonable volume of her goods, arising from the trade. Two aspects of maritime venture have been affected by the maritime policies of governments in modern times. The first refers to the policy of nations affecting trade at the inter – continental level. A good example of this is the United States Merchant Marine Act of 1936 as amended, which spelt out the shipping policy interest of the American Nation, in covering major international marine routes with American vessels. This policy to a good extent has been copied to different levels of efficiency by developing maritime states.

The other maritime venture that is affected by government policy formulation is the inland water – ways and the exclusive economic zone now called the EEZ, or coastal waters of a state. Marine policy formulation of most developing maritime states takes the form of the imposition of a cabotage rule in her coastal waters. Under this regime, the ownership and management of vessels and crafts operating in the coastal waters is reserved for indigenes and registered corporations also owned by indigenes of the same state. This view can be termed, the rigid view, since experience has shown that these developing maritime states usually do not possess the capital in terms of sufficient number of ships to fulfil existing needs in the zone of the cabotage policy. A more relaxed view is often provided for in such policy documents allowing ships of other nations to operate in her cabotage waters pending the time such developing maritime nation attains self – sufficiency in her vessel ownership structure.

1.1. Objective / purpose of research

This paper sets out to investigate the following issues affecting the Nigerian coastal and Inland shipping cabotage policy:

(i) discover existing gaps in knowledge to which the policy makers did not give attention;

(ii) discover ways of maximizing accruable benefits from the policy; and

(iii) thirdly, the paper intends to review the historical aspects of the cabotage legislation and its influence on nations.

1.2. Significance of research

The research is aimed at discovering a new approach toward coastal and Inland shipping cabotage administration. It will also further co-operation and globalization in the administration of river crafts, coastal ro/ro short sea ships, fishing crafts, and other ships involved in rivers, lakes, canals and coastal shipping operations. Ship management firms with experience in the above area thus, have an option to globalize in a bid to take advantage of the new relaxed cabotage regime of arising developing maritime nations.

2. The cabotage policy

2.1. History of the cabotage policy

The term cabotage is often used to refer to coastal navigation and trade operating between the ports of a given maritime nation, recognized by the laws or policies of that nation as being specially reserved to indigenous operators. Most laws requiring the practice of cabotage usually require these ships to be built and operated in such countries. This requirement which was set up in the Jones Act, (section 27 of the US Merchant Marine Act of 1920) has been adopted by many developing nations who do not have the resources to either build or run their own vessels. This has made the rigid adoption of the cabotage policy requirements impracticable to most developing countries, including Nigeria.

The United States is often seen as the origin of the cabotage policy in modern times. Most nations therefore implementing the cabotage policy tend to copy or adopt that of the United States. Some other legislation in the United States supporting cabotage include the Passenger Ship Act of 1886, the Towing Act of 1940, the Fisheries Conservation and Management Act of 1976 and the 1983 presidential proclamation which created a 200-mile EEZ around the United States.

2.1.1. The origin of cabotage

What might be described as the origin of the cabotage act cannot be the Jones Act of 1920, since cabotage was in practice before this time. Kendall (1986) seems to be saying something about this when he pointed out that in 1817, “the American Congress enacted a law, which restricted waterborne trade between the states to ships built, and owned in the United States.” The implementation of the 1817 act was found to have stimulated coastwise trade to ships operating between the US Atlantic coast and Gulf coasts.

The cabotage rule in principle affects only coastal trade. However, technically the underlying principle has been extended via other legislations to affect specific trades where the government of the nation has an interest. Cargo protection policies and ship subsidy practices may all have evolved out of this policy.

2.2. Cabotage, as practiced in other nations

2.2.1. Australia

In Australia, the practice of cabotage is covered under the Navigation Act 1912. Under the act, various forms of protection which are not available to foreign flag vessels are offered to indigenous flag ships. Australian indigenous vessels that operate permanently in Australian coastal trade are issued with a licence. Foreign flag vessels wishing to operate in the Australian coastal trade are issued either a single voyage permit or a continuous voyage permit by the department of transport and regional services (DOTARS) Webb (2004).

2.2.2. New trends

Some arguments in recent times have tended towards the emergence of a new domestic shipping policy. While some argue that the cabotage policy removes competitiveness in coastal shipping, others argue that it is no more relevant in the present age. Current issues in West Africa has added the issue of local content to further requiring foreign coastal operators in the region to pick up local partners before they can operate. This issue further strengthens cabotage operations in the region. The practice is found in Ghana, Nigeria, Angola and smaller West African countries.

Hodgson & Brooks (2004) for instance has preferred the dropping of the cabotage policy for the policy of non cabotage OECD nations like U.K. and Norway.

2.2.3. India

India presently practices cabotage policy in her domestic shipping, but however, a new proposal aimed at reversing the cabotage rule has been forwarded for cabinet approval. Under this new legal regime, vessels of neighboring countries to India will be allowed to sail in Indian coastal waters (Zadoo, 2005).

2.3. Cabotage integrated backwards

The cabotage principle is an aspect of the interventionist shipping policy. Other aspects of the interventionist shipping policy include subsidy policy, a regulation policy, taxation policy, and flag discrimination policy. Arguments often presented to justify the practice of the interventionist shipping policy includes

i. economic and military security argument

ii reduction of faith in the comparative advantage theory

iii retaliatory institutionalization of policy against other maritime nations, who practice it.

Some economic demerits have often been associated with interventionism, in international shipping. These include high freight rates, large operating costs, poor services and excess shipping capacity building.

Shipping policy rules have existed since the times of the Phoenicians many centuries before Christ in the Mediterranean region. Other early aspects of shipping policies include the rules of the Oleron , the *Mare nostrum*, etc. About the 17th century, Hugo Grotius then came up with his common heritage rule for the international waters, an axiom that has stood unchallenged to date. The introduction of cabotage and the EEZ concept, however, though tends to reduce the area of influence of Grotius common heritage rule.

2.4. The Nigerian Cabotage Act

The number of vessel acquisitions at the global level is on the rise especially in the cabotage sector in which Nigeria is interested. This fact is captured in table 1.

Table 1 - World Offshore Support Vessel Order book size by number and GRT

Tabela 1 – Embarcações de apoio offshore a nível mundial,

Vessel type	Number of vessels	GRT
Anchor handling Tug	35	31,509
Anchor handling Tug/Supply	396	954,552
Crew boat	59	18,880
Maintenance/Utility vessel	41	28,984
Offshore maintenance/Utility vessel	29	217,253
Offshore support vessel	15	89,738
Supply vessel	224	617,097
Grand total	799	1,957,983

Source; Rose, 2011; Onyemechi, 2013

The country should try to maximize her vessel acquisition to enable her fully participate in her local trade.

Nigeria's Cabotage Act is known and referred to as the coastal and Inland shipping (cabotage) Act No 5 of 2003. It constitutes of nine different parts, which spells out its operating principles. The central theme of the Act however is reflected in parts II, part III, part IV and part V. Part II from its title deals with legislations that restricts vessels in domestic coastal trade to indigenously owned vessels.

Section 3 of part II of the Act unequivocally states; "A vessel other then a vessel wholly owned and manned by a Nigerian citizen, built and registered in Nigeria shall not engage in the domestic coastal carriage of cargo and passengers within the coastal territorial Inland waters, or any point within the waters of the exclusive economic zone of Nigeria." This section in intent is aimed at attracting investments in ship construction of cabotage size vessels into Nigeria. This however is not stated directly in the Act. It can be seen as an Act aimed at benefiting ship construction interests operating in Nigeria. The above requirement is watered down in part III which provides for waivers to be granted by the Minister of transport to foreign shipping interests where he is satisfied that there is no wholly owned Nigerian vessel that is suitable to provide such service. Waivers may be granted by the minister in any of the following circumstances:

a. Where the shipping company operates a joint venture arrangement between Nigerian citizens and non – Nigerians, with the equity shareholding of Nigerians in the partnership or joint venture being not less then sixty percent (60%) and such percentage is held by Nigerians free from any trust or obligation favoring the non – Nigerian.
b. The vessel is registered in Nigeria, or
c. Is owned by a shipping company registered in Nigeria and complying to the relevant provisions of the cabotage Act.

Where a waivers is granted to any of the above, it shall last for a period of one year. Waivers is the subject of part III of the Act, while part IV focuses on conditions that permits a foreign – owned vessel being co-owned by Nigerians to apply for and receive a licence. In technical terms one may state without shaking, that in the instances given above, there exists a merger option for foreign shipping companies willing to co-operate with Nigerians, in the event that they decide to partake in our domestic trade.

Section 26 spells out conditions under which a mortgaged ship may partake of the cabotage law. Such a vessel must be under charter for a term, not less then 3 years. Again, the charterer or mortgagees must meet the citizenship requirements for operating vessels in the domestic coastal trade. Prior, to commencing operations, a charterer is required to produce an affidavit sworn to by the financial institutions lending him the money in a court of superior records, certifying that the financial institutions interest in the venture is solely financial, with no intent of contracting the vessels operation to non – citizens.

Part V of the Act require all vessels intended for use under the Act to be duly registered by the Registrar of Ships in the Special Registrar for Vessels and Ship Owning Companies engaged in cabotage. The following vessel types are eligible for registration under the Act as cabotage vessels.

(a.) Passenger vessels:
(b.) Crew boats
(c.) Bunkering vessels
(d.) Fishing trawlers
(e.) Barges
(f.) Off shore service vessels
(g.) Tugs
(h.) Anchor handling tugs and supply vessels
(i.) Floating petroleum storage,
(j.) Dredgers
(k.) Tankers,
(l.) Carriers, and
(m.) Any other craft used for carriage on, through the underwater of persons, property or any substance whatsoever.

In trying to register vessels for operation under the cabotage, the Minister may demand compliance to section 23 of the Act. This section require among others, vessels registrable to be beneficially owned by Nigerians or Nigerian registered companies or be a bareboat chartered vessel under charter by Nigerian citizens, being managed and controlled form Nigeria. Or otherwise, he should ensure that not more than 40 percent of the shares and control of the company accrue to non- citizens the vessel is also required to comply with both local and international conventions.

The rest of the parts are tributary to the above listed parts. Part I deals with interpretations, part VI with enforcement, part VII with offenses, part VIII with Cabotage Financing Fund and part IX with miscellaneous.

Enforcement officers are required to be appointed by the National Maritime Authority to enforce that Act. Offenses committed under that Act carry penalties ranging from N5, 000,000 to N15, 000,000. The presence of this rule has forced many foreign shipping firms operating in Nigeria to localize through joint venture partnerships with local companies. Good examples include the joint partnership between South Asian company Bumi Armada with a local company Century group. The joint company is known as Century Bumi. The other good example is the localization of the foreign shipping firm Lamnalco to AfrikDelta.

The Act places a surcharge of 2 percent of the contract sum performed by any vessel engaged in coastal trade, to be paid into the account of the National Maritime Authority and deposited in commercial banks, made available to Nigerian citizens and shipping companies wholly owned by Nigerians.

3. Methodology

The methods applied in the research include:

(a) SWOT analysis; this involved strength, weakness, opportunities, and threat analysis of the Nigerian cabotage Act.
(b) Benefit/ cost analysis; under this, criteria for benefit maximization rules in the cabotage policy were established.

4. Report of findings

In the valuation of marine policy, one tool that has been very helpful is the social costing technique. Pillai and Paul(2011) In this approach the objective function may be set as follows:

Maximize social welfare, mathematically expressed as:

$$\text{Max} \quad \int^{T}_{O} B(t) - C(t)\, dt \qquad (1)$$

subject to constraints social benefits (B); and social cost (C)

The benefits are often reflected in social values while the costs are often viewed to reflect the opportunity cost of invested in such projects. For instance money spent in dredging a channel has the opportunity cost as , other projects that would have gulped the money. In ranking an investment with the benefit/cost ratio, the investment is seen as good if the B/C ratio is (greater than) > 1.

The above approach can be developed for use in analyzing the cabotage policy discussed above. The Nigerian coastal and inland shipping cabotage policy may be described as being hinged on the formula below.

$$\text{Max} \quad \int^{T}_{O} B(t) - C(t)\, dt \qquad (2)$$

with B(t), C(t) > O and where B(t) represents the total benefits expected to be derived from the policy, and C(t) the opportunity cost.

The benefits B(t) can be said to comprise two components:

a) Attract maximum shipbuilding capacity of cabotage size vessels into the country.
b) Maximize net attracted freight rates brought in by the cabotage policy.

4.1. Transfer of shipbuilding technology

In the first instance, where a foreign firm exercises an option of transferring her shipbuilding technology for cabotage size vessels, to Nigeria, a new benefit maximizing criteria incorporating the gains from (b) above will emerge. This is because vessels manufactured, by the corporation will have ready market assured by the cabotage policy, and outside Nigeria, in the international market. This is covered by the part of the policy which states that only vessels, built in Nigeria shall engage in domestic coastal trade.

A mathematical function representing total benefits from this approach can be written under integral calculus as

$$\text{Max} \quad \int^{CT}_{C=o} Vbc \ \ (2) \qquad (3)$$

subject to available market.

With Vbc representing vessel building capacity, and C=o to CT representing the whole range of cabotage size vessels available in the policy.

A second option which can be exercised as part of the first will be the location of the shipbuilding firm in the Nigeria Export Processing Zone (EPZ) area. This act will maximize accruable profits to the shipbuilding firm by minimizing the customs duties paid on imported materials.

Option (b) above if exercised will only affect the derivable freight rate earned through a merger, or joint venture relationship between a Nigeria firm and a foreign owned shipping firm.

The number of vessels captured into the cabotage framework is visible through the following database (Table 2).

Table 2 - Cabotage vessels operating in Nigéria

Tabela 2 – Navios de cabotagem que operam na Nigéria

Company	Number of vessels	Registration type
1.Akpos Marine Nigeria	5	Nigeria
2.Bourbon Inter Oil Nigeria	5	Temporary
3.Seabulk Offshore Nigeria	8	Temporary
4. Lamnalco Nigéria	20	Joint Venture
5.Sea Trucks Nigéria	67	Nigeria
6.Diesel Power Nigéria	39	Nigeria
7.Hyundai Serv. Ind. Nig.	4	Foreign
8.Walvis Nigéria	14	Foreign
9.RANGK	3	Nigeria
10.Bourbon Inter Oil	3	Joint Venture
11. West Africa Offshore	15	Foreign
12. West Africa Offshore	10	Joint Venture
13. Phoenix Tide Offshore Nig	32	Bareboat
14. Shell Petroleum Dev. Nig	121	Joint venture
15. Maersk Line	8	Foreign
16 Income Electrix	5	Nigeria
17.First Marine & Eng Serv.	6	Bareboat
18.Coastal Inland Marine Serv.	5	Foreign
19. Edison Chouest Offshore	3	Foreign
20. Milford Marine Nigeria	5	Nigeria

Source: NIMASA Cabotage Report, 2006; Onyemechi,2013.

4.2. Merger or jointly owned shipping firms

Where a foreign firm decides to take advantage of the cabotage policy through merger or joint venture agreements, the following investment analysis will apply.

The first approach will affect situations where a new venture is supplied into the joint venture agreement. The benefit from such arrangement will be given by

$$\text{Max} \quad \int^{T}_{o} Bn(t) - Ci(t)\, dt \qquad (4)$$

where Bn represents the net derivable profit or net freight earnings from the joint venture agreement, and

Ci(t) represent the invested capital or cost of construction of such vessel.

The range O to T represents the time frame for which the total number of vessels employed in the venture is expected to last.

In a second approach, a shipping firm abroad holds a joint venture agreement with a firm registered under the Nigerian cabotage law, in hope of transferring vessels billed for lay-up to such joint-venture company. In this situation the vessel continues to earn freight instead of paying port changes or berthage. The benefit derived from this second joint venture is thus multiplied or doubled.

4.3. Real -options valuation

This valuation principle assesses the effect of chances in determining return on capital invested. It divides the capital outlay into two components, the deterministic component taken care of by the discounted profit and a stochastic component taken care of by the mean of the standard deviation of the errors assessed over a given time period. Real option valuation is widely applied in shipping financial appraisal.

4.3.1 Nigerian coastal & adjacent river transportation networks

The transportation network in Nigeria's coastal waters can be subdivided into the following sub-sectors:

i) - **Delta River network**. This comprises of the rivers and creek networks around the oil and gas rich delta coastline of Nigeria. The region is a commercial nerve centre that houses major oil companies in the area. Major export bases like oil terminals, and harbors for both import and export goods are also based in this region. Marine transportation options in this region include oil supply vessels (O S V,s), fishing vessels, barge transport vessels, tugs, dredgers, coastal tankers, bunkering vessels, both company-owned and private crewboats, passenger vessels etc. The region is bounded by the newly declared 200-nautical mile Exclusive Economic zone (EEZ)-

ii) -**The Exclusive Economic Zone**. This region is currently a very active region with oil prospecting activities by major oil concerns like Shell Petroleum Development Company (SPDC), Exxon Mobil, Nigeria, Chevron /Texaco among others, fishing activities by both local and international companies, marine traffic by major international shipping lines, and air transportation by company-owned helicopters serving the major oil firms flying between rig & land base, etc. Also included are security operations by the Nigerian Navy and other agencies. Marine transportation options in this area covers all the cabotage size vessels and international vessels in other trades.

iii) - **Imo river network, cross river network and creeks of Western Nigeria**. These form navigable waterways for barge transportation, ferry services, and log transportation. Short sea ro/ro shipping services, hotel boats for tourism and fishing crafts are very good trade options in this region.

4.3.2. Emerging coastal cities & commercial nerve centres

A - Lagos

The largest of these cities is Lagos, a commercial nerve centre of trade & commerce, the largest Nigerian port city with major shipping lines located therein. The headquarters of major oil companies are also located here. Major operating fishing companies in the country are here. The headquarters of the National Maritime Authority is also located here.

B – Port Harcourt

This is the largest oil city in Nigeria. It has Shell's Oil Export terminal located at Bonny: The Nigeria LNG operations base is also located here. Other major oil corporations also operate from here. The city has a port as well as fishing terminals.

C - Warri

This is also an oil city. Major oil firms in this area are Chevron/Texaco operating from Escravos and Shell Petroleum Development Company of Nigeria, operating from Forcadoes terminal.

D - Calabar

This city houses the first Nigerian Export Processing Zone. It is an attractive port city and a commercial nerve centre. Exxon Mobil's terminal is located at Qua Iboe off Calabar.

E - Major commercial hinterland centres

These include Aba, a textiles base & industrial centre, Onitsha, a major importing city. Benin, Kaduna, Owerri, Ibadan, Kano, Umuahia among others.

4.3.3. Developed maritime nations & cabotage policy

An emerging opportunity for developed maritime nations trading in cabotage size vessels is dependent on how to maximize benefits from this present regime of cabotage polices. Opportunities in developing maritime nations operating the cabotage rule, should be sought out, and best strategies for enhancing such opportunities to the general benefit of all, evolved.

The Canadian experience in the great lake district and St Edwards water ways linking the Atlantic and interior

Canadian cities is of a good advantage in this new era of global co-operation. Companies operating in this district may decide to globalize their activities by signing new joint venture agreements with Nigerian carries operating in the cabotage waters, in view of searching out new trade opportunities. Other developed countries in this category among others will include shipping operators in the United States, Japan, Britain, France, Norway, Australia etc.

4.4. SWOT analysis of the cabotage Act

The acronym SWOT means strengths, weaknesses, opportunities & threats. It is an analytical tool used in strategic management to evaluate and appraise policies of nations or corporate bodies. Here, we are going to identify the strengths and weaknesses, as well as the opportunities and threats associated with the cabotage policy.

4.4.1. Strengths

The strengths of the cabotage policy as practiced by Nigeria are founded on the following basic facts:

a) The ownership and control of activities in shipping at the coastal level will be in the hands of the indigenes that stand in a position to research, invest and thus improve shipping activities in their country.

b) The involvement of the indigenes will force the investment institutions such as banks to be interested in ship financing, hence stirring up and supporting development in this sub-sector of the economy.

c) The leadership position of the indigenes in this subsector will place them in a position to attract other foreign investors into the industry.

d) Individuals and corporate institutions may invest in shipbuilding and construction in the country in hope of utilizing the market offered by the cabotage policy.

e) A transfer of the shipbuilding technology from the attracted shipbuilding technology sector to the indigenes will occur.

f) More jobs will be created in the maritime sector, to the full benefit of indigenes trained in marine related activities.

g) The rate of growth of commerce in coastal shipping operations is expected to increase maximally.

4.4.2. Weaknesses

The weaknesses of the cabotage policy as practiced by Nigeria includes inter alia:

1. Ship repair facilities at the local level are presently poor. As such more energy should be focused in both human and facility development for both operations and repair if the Act is to make the necessary maximum impact on development.
2. The huge investments required to finance necessary shipping activities in the coastal sub-sector may not be available. Proper implementation of the policy at as a rigid rule would therefore be impossible. The absence of the necessary funds will thus force indigenes to resort to several joint venture agreements with owners who certainly come from more developed parts of the world. The rigid rule argument eliminates the participation of foreigners. This is not the case with Nigeria where the foreign operators have the option to localize through available local partnerships.

Existing foreign companies operating in the region will have to decide, either to comply with the requirements of the cabotage Act or pull out their resources. Presently, these companies are converting to local companies through available joint venture options made available in the Act.

4.4.3. Opportunities

Several dimensions of opportunities are created by the cabotage policy. These include:

a) The whole lot of shipping investment opportunities in the following areas; passenger vessels, crewboats, bunkering vessels, fishing trawlers, barges, offshore service vessels, tugs of all types, dredgers, tankers, carriers, floating petroleum storage etc. are thus open for investment, by virtue of the Act.

b) The return on investments made in these areas most of which are valued in dollars will thus be open to both indigenous and foreign joint venture partners of indigenous investors, in the cabotage controlled trade.

c) A new market of investors through research will come to learn about opportunities in the area, thus stirring up further investments.

d) The Cabotage Vessel Financing Fund made available to indigenes by the policy will thus enhance their position to participate in the lucrative business of shipping.

4.4.4. Threats

Threats of the cabotage policy may be summarized as follows:

a) There is the fear that foreign investors may want to pull out of the vicinity in favour of fair competitive trade policy nations. Fair competitive trade policy argues that trade must be on equal basis between indigenes and non-indigenes.

b) The freedom of agencies such as oil companies to award contracts like time-charter contracts will be highly de-limited by the policy, since such contract types can be awarded only to individuals or corporate agencies which qualify.

5. Conclusions

A good study of the historical aspects of the cabotage policy and the evolution of benefit maximizing principles associated with the policy has been performed in this work.

While only very few nations have refused the practice of cabotage in favour of policies that allow competitiveness in shipping, a good number of nations in the world have embraced the practice of cabotage. Some have even practiced it for many decades if not centuries to date.

The rising problem presented by the cabotage policy is simply how to maximize benefits from the policy. Suggested strategies as contained in this work is hinged on global co-operation between ships of the cabotage size, owned by companies in the developed maritime nations and shipping companies operating in the cabotage waters of a country operating the cabotage policy.

The new regulation being discussed by the Indian parliament which claims, it wants to introduce competitiveness to the cabotage regime is merely an extension of the cabotage rule from the usual country level to the regional level. Such a policy if captured by many more nations will improve on the benefit maximization principle realizable from cabotage waters.

There is no doubting of the fact that the cabotage policy as adopted by many developing nations is undergoing a variety of changes. While the Australian version of the cabotage is increasing foreign participation through the award of more (SVP's) single voyage permits and (CVP's) continuous voyage permits, that of India intends to operate in the sub-regional basis. Foreign participation thus, is a rule which although not directly expressed by some nations, is seen as a fundamental requirement to the survival of the cabotage rule.

The Nigerian cabotage policy recognizes this by creating options for the Minister of transport to involve foreign ships in the cabotage trade provided they operate a defined joint venture relationship with Nigerian ship owners.

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Animal welfare concerns at a fish farming operation in southeastern Brazil*

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ABSTRACT

Concerns for the welfare of fish during the farming/production process is in its infancy when compared to other species. This is due to disputes in the interpretation of characteristics that suggest awareness in fish, a concern that is somewhat widespread among consumers and producers. Through questionnaires, this study aimed to highlight what the members of a fishermen's association (that farm Tilapia and Robalo Peva) understand about the welfare of fish, and whether it is considered during the production process. In addition, although there are still many controversies, this perception has been changing in recent years, in part due to anatomical, physiological and behavioral evidence that suggest fish are sentient (are aware of sensations, have subjective feelings). Moreover, as the consumer has become aware of the issues, concern for animal welfare has increased, leading to a need for the market to adapt to these requirements.

Key words: Fisheries, Aquaculture, Animal welfare, Fish farming, Sentient

RESUMO

Considerações quanto ao bem-estar animal em uma operação de cultivo de peixes no sudeste do Brasil

A preocupação com o bem-estar dos peixes durante os processos a produção e processamento do pescado é embrionária se comparada com outras espécies, devido à existência de controvérsias sobre a interpretação de características que sugerem a consciência deles. Assim, através de questionários, o presente estudo tem por objetivo, evidenciar o que os membros de uma associação de pescadores, que cultiva tilápias e robalos-peva, conhecem sobre o bem-estar animal, e se ele é considerado durante o processo de produção. Sendo que, embora ainda haja várias controvérsias, essa situação vem se alterando nos últimos anos, devido a evidências anatômicas, fisiológicas e comportamentais que sugerem que eles também são sencientes (tem capacidade de ter consciência de sensações, ter sentimentos subjetivos). Além disso, à medida que o consumidor tem consciência do assunto, o bem-estar animal tem se tornado uma preocupação crescente, que conduzirá a uma necessidade de adaptação do mercado quanto a essa exigência.

Palavras-chave: *Pescadores, Aquicultura, Bem-estar animal, Piscicultura, Sencientes.*

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1. Introduction

Concern for the welfare of animals (non-human) has existed for a long time, however, throughout the years; various ideas have tarnished this concern by questioning the capability for suffering and awareness in animals (Volpato, 2007). Since Harrison (1964) published his work that looked at excessive abuses in the commercial production of animals, scientific concerns about animal welfare have increased, especially regarding mammals and birds. However, interest in this subject as it relates to welfare of fish, is relatively recent (1990s) and increased at the beginning of the 21st century (Anonymous, 2006; Galhardo & Oliveira, 2006; Volpato, 2007).

Studies concerning the welfare of fish began after Rose (2002) published his work on the neurobehavioral nature of fishes and the question of awareness and pain. This work led to great fanfare in scientific circles. According to the author, there are no anatomical evidence to justify the feeling of pain in fish and any future work that proposition for the existence of consciousness in fish (or other neurologically-comparable vertebrate species),, should provide a compelling empirical basis. Furthermore, also states that the perception of pain or any other physiological only have implications for the well-being of fish, if achieving elevated brain levels (Volpato, 2007).

Based on these assertions, a series of studies have attempted to demonstrate the basic neuroanatomical and physiology of pain perception in fish. The work started in the laboratory of Victoria Braithwaite (Odling-Smee & Braithwaite, 2003; Sneddon *et al.*, 2003; Brown & Braithwaite, 2005) has contributed to the empirical support of sentience in fish, serving as a basis for studies by Sneddon (Sneddon, 2002, 2003a,b; Sneddon *et al.,* 2003). From the methodological point of view, both Braithwaite and Sneddon (as well Rose) tested for empirical evidence inferring that fish are sentient beings (Volpato, 2007) using the same methodology.

Other authors (Sandoe *et al.,* 2004; Dawkins, 2006; Duncan, 2006; Volpato *et al.,* 2007) have shown the inability of these empirical methods to demonstrate sentience in non-human organisms, including fish (Volpato, 2007). However, Volpato *et al.* (2007) noted that the method is also unable to prove the absence of sentience. This lead to a the suggestion of an ethical premise in which fish may be sentient beings, and while not having to prove whether they are or not, common sense would dictate that these animals should be treated as such. Moreover, the largest body of scientific studies points indirectly to the idea that fish are sentient beings (Volpato, 2007).

Currently, the literature recognizes that in order to justify the welfare in fish, it would be necessary to show that these organisms are aware of a state of distress or discomfort. At the most rudimentary level of consciousness (the basis of concept of sentience), animals have to the capacity to perceive basic processes such as pain, heat, cold. Sentience is an attribute that animals must have in order for people to be concerned for their welfare (Volpato, 2007).

Indeed, concern for the welfare of the fish during the production process is not very common among consumers and producers as suggested by the scant literature on the subject, more specifically in the area of animal welfare (Rollin, 1995; Fraser & Broom, 1996; Benson & Rollin, 2004; Vaarst *et al*., 2004; Carneiro *et al.,* 2007). However, this scenario is gradually changing, with increasing international publications, reports and books devoted to the welfare of fish (Erickson, 2003; Branson, 2008; Pedrazzani *et al.,* 2007; Volpato *et al.,* 2007). In Europe, according to Vaz *et al.* (2007), this issue aroused the interest of several institutions. For example: The British Field Sports Society (BFSS) commissioned a review of the scientific literature regarding the welfare of fish (Pottinger, 1995). In 1995 the European Aquaculture Society started organizing debate on this topic at its conferences.

However, with respect to Brazil, the first law that addresses animal testing was passed in 1934 (Decree n.º 24645 of July 10, 1934). This law established measures for the protection of animals and for the first time the State recognized the need to protect all animals in the country (Art.º 1). However, most of this article focu-ses on large animals (horses and cattle) (Vaz *et al.,* 2007).

With respect specifically to fish, there are still no relevant regulations regarding welfare practices that take into account the welfare of fish. Probably because the debate on the welfare of farmed fish, only begins to be established and taking into account the few works dealing with the subject (Freitas & Nishida, 1998; Volpato & Barreto, 2001; Vaz *et al.,* 2007; Viegas *et al.,* 2012).

This study focuses on demonstrating what the members of a fishermen association (who grow tilapia and robalo peva) think about sentience and fish welfare at slaughter. This will help us determine if the topic is being considered during the commercial production of fish.

2. Materials and Methods

The study was undertaken in the traditional fishing community of Pedra D'Água (18° 43' 05.86"S and 39º 48' 50.38"W) in São Mateus, ES, Brazil. The community is involved in cage-cultivating fresh water estuarine fish, specifically tilapia (*Oreochromis niloticus*) and Robalo Peva (*Centropomus parallelus*). Study site selection was based on economic, social and technological need of the community, as well as partnership between the Centro Universitário Norte do Espírito

Santo (CEUNES), the Federal University of Espírito Santo (UFES) and APESAM (Fishermen's Association of São Mateus), located in the community in question (Figure 1).

Based upon previous observation/knowledge of the local fish production process, interviews and literature search, we designed a questionnaire specifically designed with the tilapia culture in the area. There was monitoring of the performance and functionality of the activity (Freitas *et al.,* 2009). Being that The Fishermen Association of São Mateus (APESAM – Associação dos Pescadores de São Mateus) consists of 22 members and has 164 cages for fish farming. This activity is an alternative income for fishermen, especially during the closed fishing periods.

Sampling was performed was non-probabilistic and by accessibility, using elements accessible for data collection, looking for reliable information that look in to account efficiency that represented the true characteristics of collected data (Gil, 2008).

The questionnaire was structured following an order of pre-established questions, whose order and wording remained constant for all persons interviewed. This questionnaire was individualized and possessing open and closed ended questions, the questions sought to identify the perception fish farmers had about slaughter methods, to identify shortcomings in the welfare of the fish and its influence on their commercial production.

This method proved to be the fastest and most efficient way of understanding the key aspects of the production chain, seeking clarifies what the fishermen knew and expected of the aquaculture activity. (Gil, 2008).

The interviews took place during a visit to the headquarters of APESAM on May 31, 2012. The data were

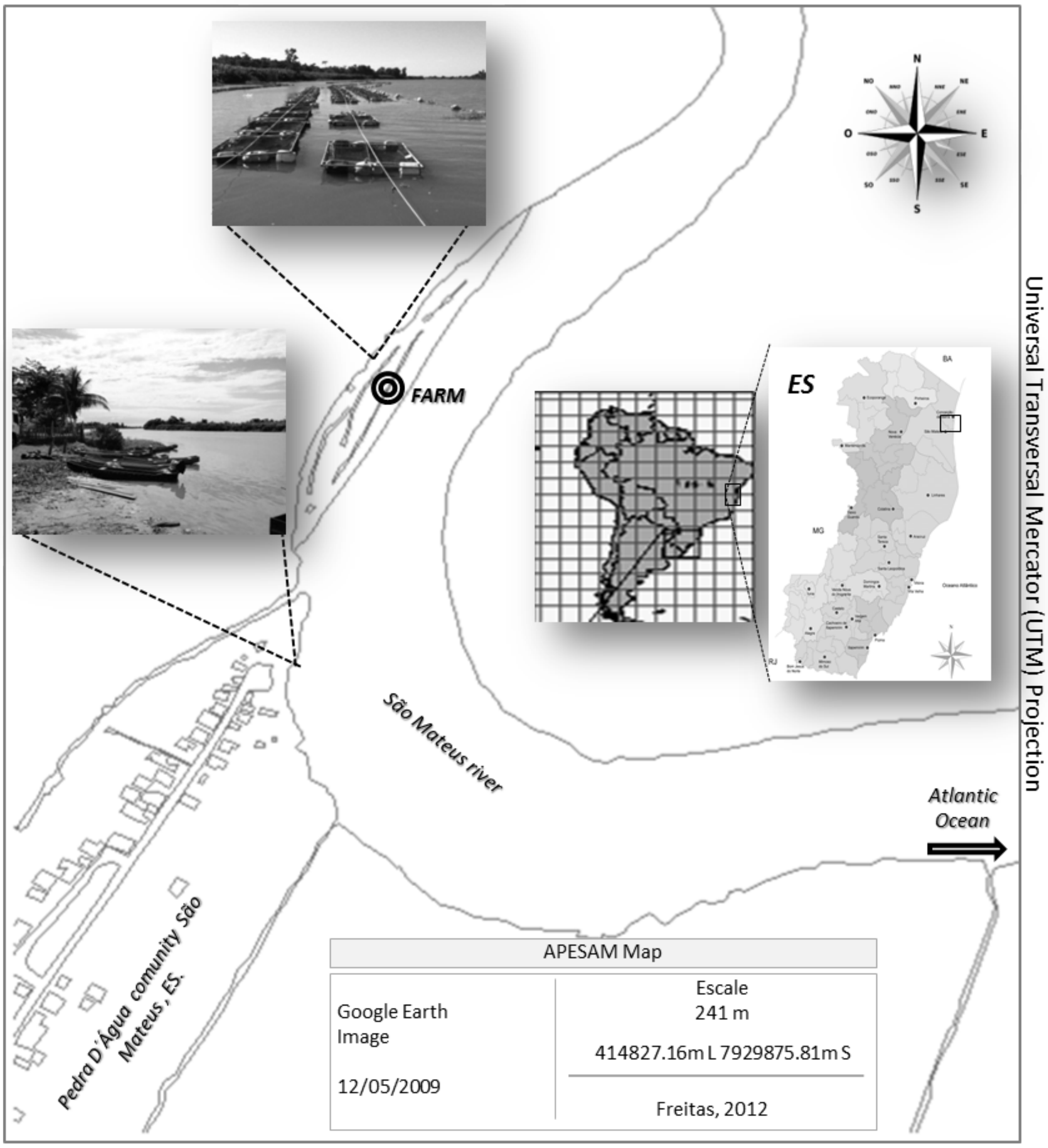

Figure 1 - Study area overview.

Figura 1 - Visão geral da área de estudo.

gathered, between the months of May and July 2012, from nine individuals that were members of the association and that were available on site. Due to the pattern of responses compiled from the questionnaire, we determined the number of interview was satisfactory, on account of the patterns of responses obtained through interviews and there was no need to return on for additional interviews.

3. Results and Discussion

The present study suggests that, even without scientific proof of sentience in fish, fish farmers treat them humanely. This was substantiated through interviews, where according to the persons involved, the proper handling of fish resulted in higher weight, reduced contraction of diseases and reduced mortality. This appeared to be influenced by potential concerns over welfare (targeting the commercial side of the activity) and the fact that consumers did desire that the fish to be treated humanely (Figure 2).

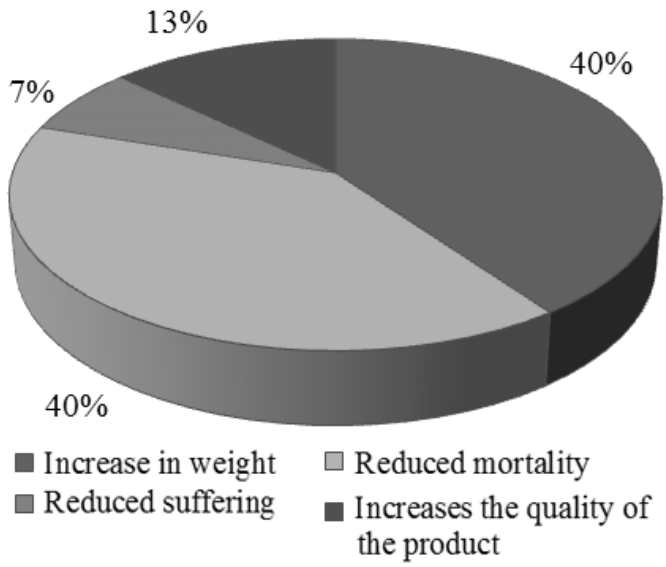

Figure 2 - Percentage of different reasons given by individuals tested of why the welfare of commercially produced fish is important.

Figura 2 - Percentual das diferentes razões apresentadas pelos indivíduos testados justificando a importância do bem-estar dos peixes na produção comercial.

As matter of fact, most scientists, philosophers and members of the public accept the idea that most animals are sentient (Turner, 2006). According to research conducted by Molento *et al.* (2001) and Bones *et al.* (2007), about 96% of people they tested believe that animals usually have "intelligence" and emotions, thought there was a lesser degree in recognition of sentience of fish than other animals.

Moreover, as society begins to recognize animal suffering as a relevant factor, an economic value is placed on animal welfare that becomes an integral part in the calculation of the economic value of animal products. There are studies that suggest that in societies that are more conscious of the importance of the welfare of commercially produced animals this can have significant cost-benefit ratios (Molento, 2005).

The expenditures associated with improving the quality of life of animals were a limiting factor for progress in the area, as the producers did not want to commit to higher expenses if the well-being was not a commodity. This situation has been changing animal welfare has become a growing concern in many countries (specially the most developed), with increasing societal demands for improvement in the quality of life. Thus animal welfare will be set up to as a non-tariff barrier of great importance (Molento, 2005; Gameiro, 2007).

In order to discuss welfare objectively, we need a better context, since the concept itself is interpreted in different ways (Dawkings, 1998), though most definitions fall into three categories, each addressing different aspects of significance. According to the Fisheries Society of The British Isles - FSBI (2002), the categories are based on feeling (what an animal feels being free from negative experiences while promoting positive experiences), role-based (centered on the animal's ability to adapt to the environment), and type (where the environment of each animal species is considered, and the captive environment should be a similar as possible to that found in the natural environment).

Regarding the category of feelings, only one person disagreed that fish could feel fear, but in general, the results suggest they were aware that fish have the ability to feel. In addition, the results suggest that the individuals interviewed try to prevent that the fish they handle meet predators, reducing the handling of fish and to avoid scaring the fish with sounds and disturbances in the water. Pedrazzani *et al.* (2007) reported that that under certain circumstances fish feel stressed, increasing the evidence that fish can sense and consciously respond to different stimuli (similarly to mammals) from the point of view of physiology and psychology.

Stress can be defined as a condition in which the dynamic equilibrium of the body (homeostasis) is threatened / disturbed by a stressor stimulus (Wendeelar Bonga, 1997). These factors can be of many types which can be divided into three main areas: the physical (such as shipping, handling or confinement), chemical (such as contaminants, low oxygen or low pH), and those perceived from the environment by the animals (such as the presence of predators) (Barton, 1997).

The action of these factors may produce effects that threaten or disturb the body's balance, or cause a range of responses (such as remedial action and/or adaptive actions), enabling the animal to overcome the threat(s). Importantly, if the animal is subjected to intense and constant stress, the physiological response may lose its adaptive value and become dysfunctional, causing permanent damage to health and well-being (Carmichael, 1984).

In general, similar to occurrence in other vertebrates, we can name three levels of reaction/response to a stressor. The first would be an alarm reaction, which includes neuroendocrine changes resulting in the release of catecholamine and cortisol. The second attempt would be resistance and adaptation as a result of the levels of hormones released, altering movement of the rates of hormones, neurotransmitters conversion rates, the cardio respiratory rate and mobilization of energy reserves. The third stage is a state of exhaustion, including immune changes and those affecting in the rates of growth and reproduction, often leading to death (Galhardo & Oliveira, 2006).

In addition, stress impairs growth due to effects on metabolism and endocrine changes that regulate growth. It is worth noting that the link between growth and fish metabolism is complex and less well understood that other mechanisms such as, for example - playback control (Silveira *et al.,* 2009). In general, these adverse conditions could lead to a significant reduction in the productivity or development of the individual, which makes well-being of primary concern.

One way to address stress reduction was to maintain an environment similar to that found in nature. In this regard, members failed to show any relevant concern. According to them, it is difficult to adapt the culture environment (cages) to resemble the natural environment due to space constrains, as fish in the natural environment would have more "freedom". However, the maintenance of similarity between environments is not only limited to the issue of space.

In this regard, aquaculture activity is strictly dependent on the existing environment (and hence the ecosystem) in which it operates (Valenti, 2002). Water quality is an essential factor for the maintenance of an adequate environment, and according to Pedrazzani *et al.* (2007), environmental factors that are the focus of attention of research on stress in fish, both by industry and by research groups in welfare.

Another point addressed were the methods of slaughter, which is considered by Viegas *et al.* (2012) to be one of the greatest stress factors in fish production. All members interviewed reported that there were reprehensible ways to cull fish, citing as an example, "striking the head of the animal." The interviews listed five other methods that respondents scored them according to their opinions (just as cruel, cruel or too cruel). Figure 3 presents each method and their ratings.

In this regard, some authors claim (regarding warm-blooded animals such as mammals and birds) that it is common to address welfare as a factor for both production and slaughter and as such, it has been established that unconsciousness/desensitization should be rapidly induced without neglecting the welfare and meat quality (Lambooij *et al.,* 2002; Van De Vis *et al.,* 2003; Terlouw *et al.,* 2008; Andrade *et al.,* 2009; Santana *et al.,* 2009; Viegas *et al.,* 2012).

According to Pedrazzani *et al.* (2007), the slaughtering techniques of fish have been carefully studied in order to look for improvements regarding safety procedures, quality control of the final product and minimizing the time required to kill the animal and to reduce emotions (such as fear and pain) during the process.

Traditionally, ease and reduced cost were the two main factors considered in the choice of slaughter methods for fish. But traditional methods, such as suffocation (in air or on ice), evisceration or heat shock are not considered humane, because they cause unnecessary suffering,

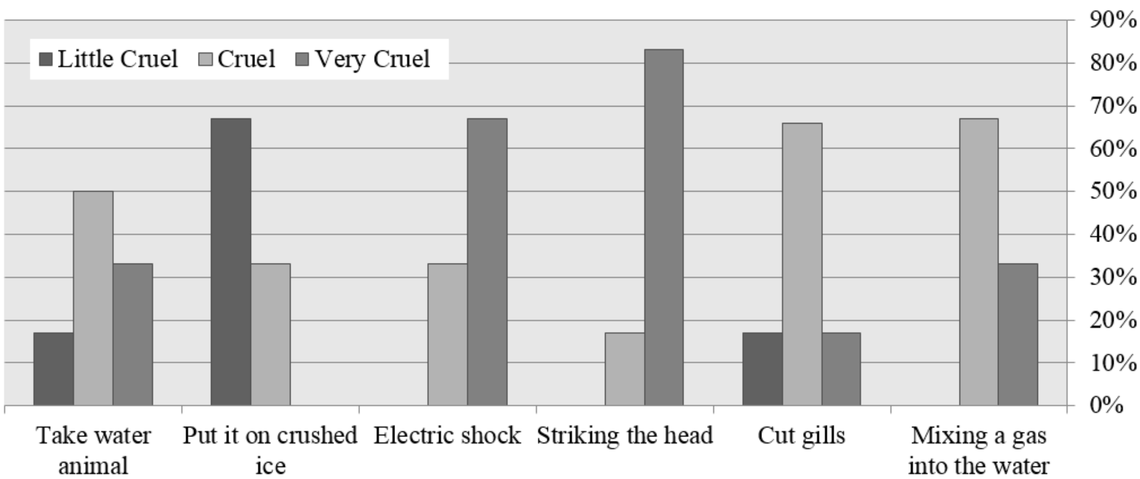

Figure 3 - Classification of methods of slaughter.

Figura 3 - Classificação dos métodos de abate.

pain and stress, additionally diminish the quality of the product during storage (Viegas *et al.,* 2012).

Furthermore, according Poli *et al.* (2005), the chemical reactions resulting from pain and stress at slaughter reduces the time to the onset of rigor-mortis in fish. Pain cause another set of reactions, which changes the pH of the flesh to nearly neutral, accelerating the action of the enzymes and promoting bacterial growth, resulting in a faster degradation of the fish. Studies by Roth *et al.* (2002) show the differences in the quality of post-harvest fish using different methods of slaughter.

In general, we can conclude that the methods that cause the least amount of suffering and provide better meat quality are: stunning by electric shock, cranial percussion and anesthetic overdose. The killing of fish by suffocation in air or with ice, heat shock, narcotic gases or by salt bath caused too much stress and have significant effects on meat quality. Thus, it is not possible to recommend a single slaughter method to be used in several species of fish, making further research on the topic necessary (Viegas *et al.,* 2012).

Another point of discuss was how to identify welfare shortcomings for fish. According to the members, a lack of well-being in cultivation was identified by excessive mortality, disease onset, atypical appearance, atypical behavior, and poor weight gain and color variation in the fish. According to Vaz *et al.* (2007), the bond between well-being and health is complex. If a fish showed signs of illness, this usually suggested that the cause might be associated with reduced state of well-being. However, this association may not be entirely true, as health-related welfare may be compromised for other factors.

The causes of fish diseases are complex and the risk increases when environmental conditions are poor (FSBI, 2002). However, it would incorrect to say that diseases are the result of poor growing conditions as even in a great environment for fish farming, fish contract diseases and eventually die.

Regarding the origin of topic, there was virtual unanimity in the interviews on three items: the market (distribution channel requiring), people (consumers are more concerned with the proper treatment of animals) and the University (science has shown that the welfare of animals is important).

As a scientific concern, the animal welfare owes its origin to public concerns about how animals are treated in captivity (Galhardo & Oliveira, 2006). The dissemination of research confirming the sentience of animals makes the public more about the origin of their product. Therefore, the market must adapt to customer demands and sell fish that were grown under humane conditions. According Carneiro *et al.* (2007), the recognition of sentience in the fish population can be an advantage for the market, as products from farms employing humane conditions (that minimize suffering) may serve to establish a price differential when selling these products.

4. Final Considerations

Fish welfare is an area with where there is little literature available in Portuguese. Questions about suffering and pain are still controversial and no specific legislation exist governing methods of slaughter for fish. Ignorance on the physiological mechanisms in fish leads researchers to compare them with other species, especially mammals, which appears to be inappropriate. However, sentience (in and of itself) is suffering for us to worry about the welfare of some organism.

Furthermore, it is observe that the implementation of production systems that provide a high quality of life for animals resulted in significantly increased production costs, which served as a limiting factor for the development of welfare awareness. On the other hand, as the demand for products produced with concern for animal increases (because of information, awareness and public perception), wellness's may become a commodity.

The present study revealed that knowledge of the subject was not wide-spread enough to affect aquaculture, though as a matter of ethics or as an effort to improve productivity, farmers were concerned with well-being, which suggested that this could be the beginning of forward progress. On must remember that welfare was not necessarily associated with improvements in productivity, but for those involved in fish farming, it directly affected the mortality and fish weight, which in turn influenced productivity. Therefore, with respect to concerns about the welfare of fish, it would be essential to maintain a suitable is necessary for both a suitable environment for farming and an appropriate method of slaughter, resulting in lower stress levels which directly translate into better quality fish on the market.

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Artisanal fishing and local conflicts: the case of the 'Pedras de Una' fishing community, Bahia, Brazil*

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ABSTRACT

Artisanal marine fishing is practiced throughout all the coastal cities in the southern region of the State of Bahia (Brazil); it provides an economic and cultural base of support for local families. Using action-research as an investigatory method while treating traditional knowledge from the actors in the region as an indispensable information source, this study aimed to identify the main socio-environmental conflicts that exist in an artisanal fishing community located in the south of Bahia, Brazil. The research methods used in this article, starting with the action-research that allows the researcher to have access to the community with a view to jointly look for solutions to specific problems, following a cycle where there is systematic oscillation between actions in the field of practice and its investigation. In this way, it was possible for the authors to provide educational assistance which included performing diagnostics, training initiatives, productive structuring, introducing new income sources and searching for markets for the fishermen's products, and at the same time, undertaking socioeconomic and environmental research at the heart of the community. Thus, the authors were able to verify that the local fishing environment is considered, by local fishermen and those from other regions, as one of the major fishing areas in southern Bahia. This characteristic means that the situation is dichotomous, because on the one side it is a matter of interest for artisanal fishermen in the local community, on the other hand, other fishermen from different regions of the country end up being attracted in order to catch fish, thereby generating conflict among local artisanal fishermen. The action-research method made it possible to verify six types of conflict: i) conflict with recreational amateur anglers; (ii) trawl fishing on the beach; (iii) using the net method for catching shellfish; (iv) picking up shellfish while they walk on the surface; (v) reluctance to using safety equipment; (vi) closed season for snook fishing. When focusing on the relationship with amateur fishermen it is possible to see, according to native fishermen, that these individuals can contribute to the local stock depletion due to the practices adopted by these fishermen; which therefore makes this conflict of primary importance among all the others that were analyzed. It was noticed that supervision and law enforcement by competent bodies is a rare thing in this analyzed fishing environment and thus, the fishermen seek partnerships through their association with various regional actors in order to find solutions to conflicts and to encourage community development.

Keywords: south of Bahia; snook; traditional knowledge

RESUMO

Pesca artesanal e conflitos locais: o caso da comunidade de pescadores de "Pedras de Una", um sul da Bahia, Brasil.

Na região sul do Estado da Bahia (Brasil), a pesca marinha artesanal é praticada em todos os seus municípios costeiros, sendo responsável pelo sustentáculo econômico e cultural das famílias locais. Utilizando a pesquisa-ação como forma de investigação e considerando o conhecimento tradicional dos atores da região como peça indispensável no levantamento das

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informações, o presente trabalho objetivou identificar os principais conflitos socioambientais existentes em uma comunidade de pescadores artesanais localizada no sul da Bahia, Brasil. Através da pesquisa-ação, os autores puderam realizar ações de extensão as quais englobam realização de diagnósticos, ações de capacitações, estruturação produtiva, introdução de novas fontes de renda e busca de mercado para os produtos dos pescadores, e concomitantemente, realizar pesquisas socioeconômicas e ambientais no seio da comunidade. Dessa forma, foi possível verificar que o ambiente pesqueiro local é considerado, pelos pescadores locais e de outras regiões, como um dos principais pesqueiros da região sul da Bahia. Essa característica acaba sendo dicotômica, pois de um lado é interessante para os pescadores artesanais da comunidade, por outro, acaba atraindo pescadores de diversas regiões do país para captura do pescado, gerando situações conflituosas com os pescadores artesanais locais. A pesquisa-ação possibilitou verificar seis tipos de conflitos: i) conflito com pescadores amadores; (ii) pesca de arrasto na praia; (iii) uso da redinha para captura do marisco; (iv) captura do marisco no período da andada; (v) resistência para utilizar equipamentos de segurança; (vi) período de defeso do robalo. Com destaque maior para o primeiro conflito.

Palavras-chave: *sul da Bahia; robalo; conhecimento tradicional*

1. Introduction

Due to fishing being considered to be one of the oldest productive activities in human existence, it took on large dimensions, primarily because of its dynamism and complexity (Mazoyer & Roudart, 2010). Along with its development, fishing has generated different situations, on the one hand it represents an economic mainstay for several actors (Santos e*t al.,* 2012a), on the other, it has had an impact on natural resources (Berkes et al., 2001) and various socio-environmental conflicts (Charles, 1992).

Artisanal fishing, conducted by professional fisherman autonomously or within the family, or with momentary help from other partners (Oliveira & Silva, 2012), has been performed on the Brazilian coast since before colonization of the region (Santos *et al.,* 2012a). This activity is influenced by various factors, such as lack of management (Pitcher & Lam, 2010), environmental problems (Capellesso & Cazella, 2011), excessive exploitation (Colloca *et al.,* 2004; Porcher *et al.,* 2010), stock reduction in some regions (Bender et al. 2013), as well as being, susceptible to possible impacts caused by climate change (Badjeck *et al.,* 2010; Egler & Gusmão, 2014; Seixas *et al.,* 2014).

With the growing need to meet the world's growing demand for fish (Berkes *et al.,* 2001), small-scale artisanal fishing has an important role to play (Tubino *et al.,* 2007). Artisanal fishermen are responsible for catching more than half of all the world's fish and the industry employs approximately 51 million fishermen (Berkes *et al.,* 2001), which reaches approximately 84 million people when the direct and indirect labor markets are considered (Silva *et al.,* 2013).

Due to the complexity of the activity (Fatima *et al.,* 2011), fishing has generated various conflicts (Charles, 1992). The fact that these conflicts exist has led to environmental debates which put pressure on the composition of agendas in society in order to clarify the different social uses of environmental resources (Santos, 2009).

On the Brazilian coast, one cannot see serious direct or apparent conflict among users in coastal communities, however, there is apparently a division in terms of marine space caused by the restrictions imposed by different technologies used by fishermen (Begossi, 2006), favoring those who have the best resources to the detriment of those who do not. This context makes it clear that the conflict can be interpreted in several ways, ranging from obstacles to propellers in the process of social changes (Santos, 2009).

1.1 Establishing study objectives

Conflict analysis is a fairly complex issue due to various aspects that are involved, such as natural resources, the life quality of social agents and economic growth in a determined geographical area (Brito *et al.,* 2011). When fishing activities are performed, which involves the wishes of several users, conflicts manifest themselves as one of the factors that affects the local fishing sector (Silva, 2011). This situation demonstrates that it is possible to highlight the effects of man and nature interacting when one is able to verify irregularities in fish stocks, environmental changes, or when they occur with economic losses for fishing, among other factors (Colloca *et al.,* 2004).

There is a similar situation that occurs in southern Bahia, Brazil, where coastal artisanal fishing happens along its entire coastline, which stretches over approximately 250 km. In this environment, effects from tourism, merchant shipping, amateur fishing, oil exploration studies and endogenous practices developed by local fishermen are faced with the activities of traditional communities, thereby generating a confrontational situation, demonstrating that the artisanal fishermen, due to the complexity in which they perform the activity, are more vulnerable to conflicts at sea (DuBois & Zografos, 2012).

It is noticeable that, on the one hand artisanal fishing appears to be a vital asset for the traditional communities' socioeconomic development, but on the other hand, given its complexity and dynamism, it is faced with various conflicts. In this context, this article aims to demonstrate the major conflicts within an artisanal fishing community located in the southern region of Bahia State, Brazil, where the fishing and shellfish collecting characteristics of those using the local fishing environment to extract fish and seafood are artisanal.

2. Material and methods

2.1 Characterizing the study area

The research was performed in a community that is known as ‘Pedras de Una’, located in the municipality of Una in the southern region of Bahia State, Brazil. This region has a monocultural history in terms of agricultural exportation, with cocoa being its main product (Theobroma cacao). Currently, it is seeking to achieve economic recovery after its last major crisis that was caused by a disease known as witches’ broom disease (Moniliophthora perniciosa), a crisis that began in 1989 (Paim *et al.,* 2006; Fioravanti & Velho, 2011).

The ‘Pedras de Una’ fishing community, according to local community officers who are responsible for health promotion, has a population of around 950 people, approximately 90% of which depend on fishing. This typically traditional community is located on the banks of the river Una, which includes a mangrove area and is close to the coastal strip (Figure 1). Its historical formation refers to how fishing has contributed to communities becoming present along the Brazilian coast (Diegues, 1999), with the figure of the initial agent being jangadeiro.

In the vicinity of the community, there are two environmental conservation units: the Reserva Extrativista de Canavieiras (Cardozo *et al.,* 2012) that aims to protect and promote sustainability in the use of natural resources by local communities, thereby constituting itself as a strategy of protection and coastal management (Diegues, 1999) and a necessary requirement in order to avoid conflicts over resources (Begossi, 2006). The second is the Refúgio de Vida Silvestre de Una (Castilho *et al.,* 2013; Sollberg *et al.,* 2014), which aims to protect natural environments, in order to ensure conditions that protect the existence and reproduction of species or communities of local resident or migratory flora and fauna.

2.2 Research methods

When faced with social, economic and environmental challenges, new forms of methodological approaches are required to overcome the prevailing economic points of view which have proved to be restrictive for understanding social complexity (Thiollent & Silva, 2007). In this context, this article’s research methods originate in the action-research method (Miskovic & Hoop, 2006; Thiollent & Silva, 2007), this is based on the authors’ engagement in educational initiatives in this community of fishermen and shellfish collectors in ‘Pedras de Una’.

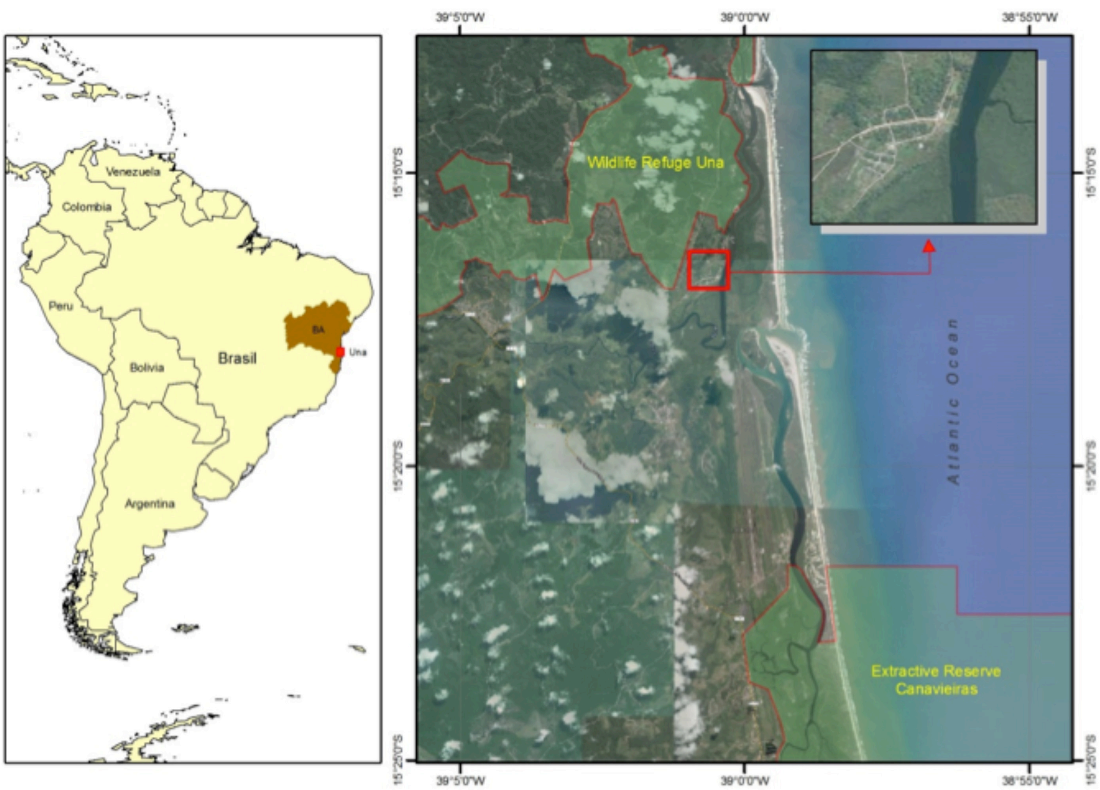

Figure 1 - Location of the ‘Pedras de Una’ community, Bahia State, Brazil.

Figura 1 - Localização da Comunidade de Pedras de Una, Estado da Bahia, Brasil.

Using methodologies that focus on participatory actions are flexible methods which enable the researcher to have access to the community in order to jointly seek solutions to specific problems (Thiollent & Silva, 2007). In this process, the action-research method follows a cycle where there is systematic oscillation between actions in the field of practice and its investigation. (Tripp, 2005). "One can plan, implement, describe and evaluate a change (...), learning more throughout the course of the process, both in terms of practice and own investigation"(Tripp, 2005: 446), this situation is demonstrated in Figure 2.

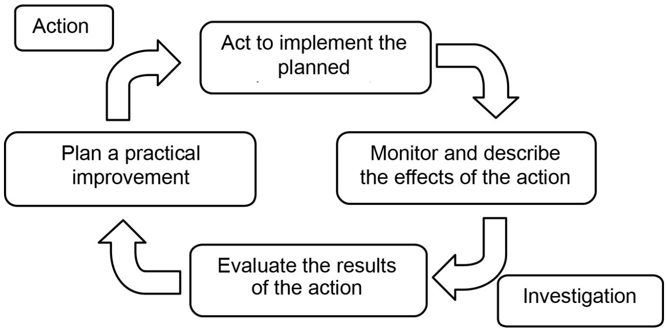

Figure 2 - Demonstrating the basic cycles of action-research. (Adapt. Tripp, 2005: 446)

Figura 2 - Demonstração dos ciclos básicos da pesquisa--ação. (Adapt. Tripp (2005: 446)

Action-research emerged as a new methodological approach within a context that is characterized by several theoretical and practical concerns that focus on the search for new forms of intervention and research (Baldissera, 2001), it is a tool that can understand the practice, assess it and question it, thereby demanding, in this way, forms of action and making conscious decisions (Abdalla, 2005), with a focus on provoking social change (Abraham & Purkayastha, 2012). Its characteristics are situational in nature, since it looks to diagnose a problem that is specific to a particular situation, this in order to achieve a practical result (Nichter, 1984; Novaes & Gil, 2009).

In the fishermen and shellfish collector community in 'Pedras de Una', results were obtained by performing initial diagnoses, training initiatives, productive structuring, introduction of new sources of income and a market search for products coming out of the community, this in order to solve a local problem, namely, the lack of income-generating opportunities. This relationship, which was initiated at the end of 2010 and is still running today, and has made it possible to install several actions in the community, as listed in Table 1, with emphasis on participation by women in these actions.

Researcher participation in the events listed in Table 1 made it possible to use action-research as a methodological conception, and also as a way to understand the local reality. The sampling method used in this article was for convenience only without any pretense to be statistically representative (Santos *et al.,* 2012b), it sought to involve as many fishermen and shellfish collectors in the various meetings held in the community. As the systematization instrument, a report was prepared at every meeting that contained the points raised during the discussions as well as the established goals. In this way, in preparing this article, these reports are used as one of the research sources.

Developing the action-research in the community enabled the use of techniques and tools which made it possible to perform surveys with local fishermen in a participative manner, this technique is known as rapid and participatory diagnosis (Verdejo, 2006; Di Ciommo, 2007;Moura *et al.,* 2012). This technique used instead sought to confront participants with previously formulated questions, these were used so as to examine the community and indicate options to improve it (Verdejo, 2006).

By using action-research, it was in line with the fishermen's activities, thereby deepening local knowledge, while also adding, as a key element in the research, the traditional knowledge of local fishermen. This understanding, such as the knowledge passed down from

Table 1 - Activities performed in the fishing community.

Tabela 1 - Atividades realizadas na comunidade de pescadores.

Actions	Amount	Public	Men	Women
Rapid diagnostic and participatory	2	32	17	15
Strategic planning	2	180	25	155
Meetings to analyze goals / outcomes	16	128	48	80
Meetings for assemblies of production units	12	50	24	26
Meetings with institutions related to fishing	5	111	45	66
Meetings to training	25	300	50	250
Totals	**62**	**801**	**209**	**592**

generation to generation, is fundamental in maintaining traditional local communities with strong cultural roots (Pereira & Diegues, 2010; Delicado *et al.,* 2012).

In this article, the traditional knowledge held by the local community was not seen as a contradiction to the scientific knowledge, but rather as a complement to it, these being, in some cases, subjected to less conventional tests when compared to laboratory ones, which were involved from research up to the practical application of the research object (Lacey, 2012). From what the traditional local fishermen pointed out during the action-research development, technical analysis was used to confirm such information.

The fishermen reported that the closed season for snook, fat snook and common snook (*Centropomus parallelus*, *Centropomus undecimalis, Centropomus* spp.) did not take into account the entire spawning period for the species, as established by Ordinance No. 49, May 13th, 1992, (Ibama, 1992), with snook being caught in the period after the period established by the law becoming commonplace. Therefore, a local fisherman was asked to monitor and register individuals that produced spawn, this was done so that the information reported by local fishermen could be verified.

Action-research, be means of researcher involvement in the community, made it possible to verify the presence of fishing-related conflicts. Upon this finding, it was decided, jointly with the community, to conduct random interviews with a group of fishermen who were fishing at the community's moorings on a certain day of the week. Thus, on February 19th, 2014, 20 randomly selected fishermen and shellfish collectors, who were berthed at the two moorings in the community, were interviewed.

In order to perform the research with the fishermen and shellfish collectors, a tool called Open Data Kit (ODK) was used that is compatible with a set of free tools based on the android system, this allows the interviewer to bring up necessary information using a mobile device. The ODK system enables the sending of forms that are filled out in the field to a database where they can be exported to software such as Excel and Google Earth, thereby eliminating the task of manually entering information that is obtained using paper forms.

Firstly, questions were asked regarding the main conflicts that the respondent understood to exist in the community. Then, after the relationship of the conflicts were specified, the relevance level of each conflict was noted by asking the fisherman which, among the cited conflicts, was the one that caused most damage to local fishing. Following this, the respondent was asked which was the second, the third, and so on.

The information collected using ODK were grouped so that the weighting assigned to each conflict by each respondent could be observed. In order to measure the weights, a Likert scale was used (Murshed-e-Jahan *et al.,* 2014) in which the lowest weight (zero) signified the greatest impact on fishing stocks and vice versa.

To classify the conflicts to their respective weight, the levels of impacts caused by conflicts jointly with what they may cause to the local fish were verified during the interviews. To do so, it was questioned what the impacts would be that could be caused by the conflicts. By doing this, it was possible to organize the impacts generated by local conflicts along with their respective weights (Table 2).

The results of this research represent a profile of a set of activities developed in the 'Pedras de Una' community. These were obtained by means of involving the authors with the community through educational initiatives and, from insights obtained locally, the research instruments were incremented in order to analyze the given point and subsequently generate feedback for the community, in a dynamic that can be shown by Figure 3 which was prepared from the model exposed by Tripp (2005).

3. Results and discussions

3.1 Characteristics of the local community

Through the diagnostics made and the action-research actions, it was found that in the 'Pedras de Una' fishing community there are fishing families whose fishing

Table 2. Weights and impacts caused by fishing-related conflicts in the analyzed community.

Tabela 2. Pesos e impactos causados pelos conflitos relacionados a pesca na comunidade analisada.

Impact	Weight	Impact Level	Action Impact
A	0 (zero)	Impacts greatly	Eliminates fish stocks
B	1 (one)	Impacts very	Decreases the fish stock
C	2 (two)	Reasonably impacts	Decreases the amount of catches by local fishermen
D	3 (three)	Little impact	Generates inconvenience to local fishermen (fishing implements of destruction by another fisherman)
E	4 (four)	Very little impact	Cause overlapping of fishermen fishing in the same and in the same period
F	5 (five)	Does not impact	Without prejudice to the fishery

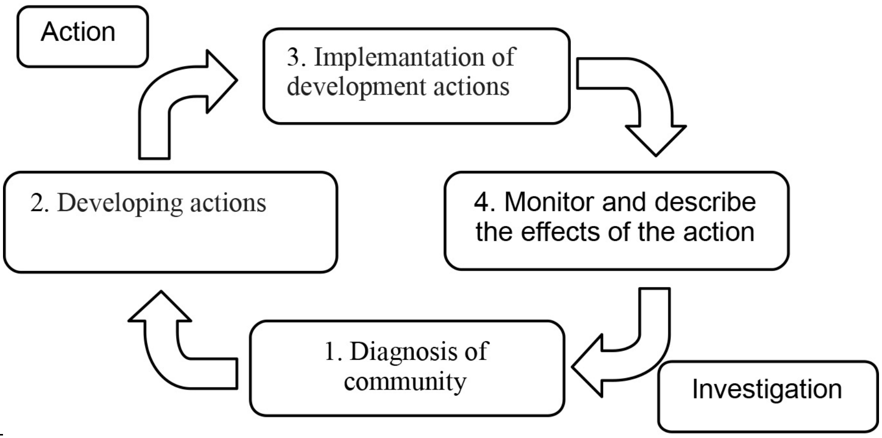

Figure 3 - Demonstrating the developed actions in the analyzed community.
Figura 3 - Demonstração das ações desenvolvidas na comunidade analisada.

practices are characterized in three different fishing methods, these being with the use of; lines, nets and cast nets, in two local environments - the river and the sea. These families also catch shellfish in the mangrove area that exists in the vicinity of the community.

The families use small canoes with a motor or paddles, rafts and small motorized boats intended mainly for shrimp fishing. Their catch is intended for consumption by the fishermen's families and any surplus is consumed by the local markets. By means of the activities performed within the community, as is shown in Table 1, it was noticed that fishing production (fish and shellfish), in the analyzed community, is faced with many bottlenecks, namely: (i) need for equipment (boats and fishing equipment) suitable for fishing activities; (ii) limited trade expertise that would provide better financial returns for their products; (iii) need for study of the mechanisms that make up the productive and commercial links in the fish productive chain; (iv) limited systemic and interconnected vision by the productive process agents; and the main bottleneck, (v) the decline in the region's fish stocks. The decline in fish stocks was emphasized by the more experienced local fishermen.

Fishing equipment maintenance is performed locally, primarily by fishermen who no longer fish to the same extent as they used to as a result of their advancing years. These individuals focus their time on preparing and repairing fishing equipment as well as on other agricultural activities as a means to provide income supplementation. The main sources of income in the community come from fishing, public service, which provides services in civil construction and a retired fishermen fund, which is a social benefit that is given citizens based on their age and/or their contribution to the social fund.

The community involved in this study has some social services, such as public health, public schools for elementary education, a municipal guard and street lighting, but is lacking in other features, for example, the telephone system is limited and communication is difficult, thereby preventing the community from having access to the internet. In order to ease these local difficulties, in 1996, the community established the Association of Fishermen and Shellfish Collectors in 'Pedras de Una' (Amepedras) which is an institution that defends local interests.

One of the greatest results achieved by this local Association, according to residents in the community, was the home construction project for artisanal fishermen. Through this public policy, the beneficiaries, about 80 families, enjoyed considerable housing improvements, leaving their previous homes that were comprised of a single space made out of wood and going to a house made of brick with better living conditions.

Through action-research, it was possible to indicate that local artisanal fishermen possess detailed knowledge regarding the local fish fauna and the morphological and behavioral characteristics of the fish. This knowledge is referred to as ethnoecology (Souza & Barrella, 2001; Carneiro et al., 2008) and can be defined as the set of knowledge and know-how regarding the natural and supernatural world, this has been passed down orally from generation to generation, developed by any society in relation to biology (Diegues, 2000), it is something perceptive in the community, especially among the more experienced fishermen, which can relate to the best fishing times in terms of the weather, tides and the color of the local water.

3.2 Verified socio-environmental conflicts in the community

The verified conflicts found by means of diagnostics and action-research were: (i) conflict with amateur anglers; (ii) conflict generated by trawling; (iii) intra-community conflicts; (iv) conflict concerning the spawning period for snook fish.

3.2.1 Existing conflicts between local artisanal fishermen and amateur fishermen.

The community involved in this study is considered, by local fishermen and by others from other areas, to be one of the best fishing waters in the region, it attracts many other fishermen from other cities, including from other states in Brazil. These non-local fishermen are equipped with fishing equipment that local fishermen do not have, for example, they have quality boats, sonar and different better equipment.

The conflict between the two types of fishermen is based on the fact that amateur fisherman take the livelihood away from fishing families in the local community. These amateur anglers can sometimes catch quantities that exceed the legally permitted amount. According to the Amateur fishing License (MPA, 2012), amateur fishermen are allowed to catch and transport a quota limit of 10 kilos of fish in continental and estuarine waters and fifteen kilos for marine waters.

In reports from local fishermen during the diagnostics and research-action activities, in most cases, the amateur anglers often catch quantities exceeding the permitted set limit. These quantities are checked by the local fishermen when the fish are brought ashore at the two small moorings in the community.

Most of the amateur fishermen, about 80% of them, according to conversations with those fishing in the analyzed community area, prefer to catch snook that, financially, for 85% of the interviewed artisanal fishers, account for a large proportion of their income, thereby classifying this as a host species. Burda & Schiavetti (2008), in the city of Itacaré, in the same region, also identified that this species is one of the most lucrative commercial species among those being fished.

Although it is of significant economic importance, the local stock of snook is found to be in decline. This statement is based on information provided by older fishermen in the community, who have spent, on average, around 40 years in the fishing industry in the area. The older fisherman unanimously stated, during the activities of the study, that over the past thirty years, they have not captured snook weighing more than 20 kilos with the same frequency as was the case in the time previous to this.

This situation resembles that which is presented by Bender et al. (2013), who used information from four generations of fishermen who worked in the Parque Municipal Marinho do Recife de Fora, in Porto Seguro, Bahia's far southern region, regarding the status of nine fish species. The authors found that for the last 50 years no larger size fish have been caught in the region, where, out of nine species of reef fish, seven had significantly declining trends.

In addition to amateur anglers catching the local fishermen's food in their environment, the local fisherman also blame the amateur anglers for damaging their fishing equipment, this is caused when they become entangled around their vessels, which creates more animosity in the relationship between the two groups. And this conflict with anglers extends to other locations beyond the 'Pedras de Una' community, the example being what happens within the Extractive Reserve (RESEX) in Canavieiras, South of Bahia, Brazil.

At the Canavieiras Resex, this conflict with amateur anglers is in fact the second most serious at the reserve, the only conflict that is judged to be more serious is the impacts generated by the captive shrimp farming. That statement was provided by a group of artisanal fishermen at a meeting of that RESEX's Deliberative Council, in which a group of amateur anglers requested a seat on that Council. On that occasion, action-research made it possible to see the conflicting scenario between the two categories of fishermen. On the one hand, the artisanal fishermen made a damning criticism to the degrading and opportunistic behavior of amateur anglers, and these, in turn, pointed to adopting conservation practices to the point of being even more conservative than the practices adopted by artisanal fishermen.

According to local fishermen, the thing that could inhibit the actions of amateur anglers in the region would be greater supervision and enforcement of the rules. However, on those rare occasions when government agencies conducted surveillance in the vicinity of the community, what was actually required from the anglers was related to them having appropriate fishing and vessel documentations, which is something that, given the abundance of resources and expertise that amateur fishermen have, is always in compliance.

The limited presence of the government in the search for solutions to the community's problems is apparent, and it enables other categories of fishermen to further deplete the local fishing stock. Something similar happened until the mid-1980s, during a modernization phase which allowed disorderly competition for catching fish, which favored the over-exploitation of resources and allowed internal conflicts to emerge (Capellesso & Cazella, 2011).

An effective way to reduce the present conflict would be to adopt rules that establish, at least, fishing limits in areas where artisanal fishermen operate. This is a model that has been adopted in Chile, for example, where registered fishermen can only fish in areas where they are registered, as stipulated by the General Fisheries and aquaculture Act of 1991, which decreased the rate of migration of fishermen from other regions in search of species to other locations (Cardona & Rios, 2011).

3.2.2 Conflicts generated by trawling.

Being an area considered important for shrimp fishing, the coastal strip near the 'Pedras de Una' community has been an disputed area by various vessels for catching the species. According to local fishermen, vessels fish in the region during the daytime and nighttime.

Trawling with motorized traction for catching shrimp is performed with fine mesh nets that are powered by engines. These nets drag the ocean floor and capture developing species and maritime flora, with no selective processes, and are therefore able to change the structure of the coastal ecosystem, thereby endangering the sustainability of target species, the accompanying fauna and the entire surrounding biological community (Sedrez *et al.,* 2013).

In addition to the pressure on the local fishing grounds, many of these vessels are equipped with cranes for large trawling nets that fish extremely close to the beach, even coming within the thousand yard limit from the shore in this location, as decreed in the Regulatory Statement No. 14, October 14th, 2004 (Ibama, 2004). According to the accounts given by the community's fishermen and therefore, by the observations achieved through action-research, this conflict extends beyond the coast and also involves the estuary formed by the bar, one of the main fishing areas used by the analyzed community.

Local fishermen believe that the lack of supervision by competent government bodies does nothing to halt the unsustainable practice that is trawling. This is a similar aspect regarding the conflict with amateur fishermen, where the absence of the government does not defend the interests of smaller fishermen.

3.2.3 Intra-Community conflicts: using the net method, catching shellfish while they are walking on the surface, and reluctance to using safety equipment.

Previous conflicts with amateur anglers and with trawling activities involved actors who were external from the community and local actors, this is different from the existing intra-community conflicts in the analyzed the net method to catch shellfish, picking up shellfish while they walk on the surface and the reluctance to using safety equipment.

The traditional model for catching mangrove crabs (Ucides cordatus) and mangrove tree crabs (Aratus pisoni), which are shellfish with economic appeal for the community, involves the person putting his or her arm inside the burrow to catch the crab, without being able to see what is at the bottom. This technique is known as braceamento (Magalhães *et al.,* 2011) or the arm method.

Braceamento is an activity that demands time, skill and courage. However, not all the actors utilize the braceamento technique to catch shellfish, they prefer instead to use the net method. This technique consists of a small net made with a braided polypropylene bag, which is placed at the entrance of the animal's burrow, so that the crab is caught when it exits its hole.

The conflict is focused on the fact that traditional shellfish collectors, who know about the importance of respecting the mangroves and their attributes, will not admit that other shellfish collectors use the net method because it does not distinguish the sex of the caught animals, since many ovigerous females and young individuals end up being caught. In addition to causing pollution in the local environment (Magalhães *et al.,* 2011), it increasingly causes the mangroves to be degraded.

It should be noted that the mangroves are important for life in the coastal area, not only for fish and crustaceans, which make up part of the mangrove ecosystem, or for their role in supporting other species that use it in their reproductive phase, but also as an element of stability and protection for the coastline (FAO, 1994). Thus, actions that have an impact, for example, using the net method, results in a decrease in the availability of raw materials, which in turn requires that fishermen search for new more distant fishing grounds and, consequently, demands more effort, resources and time (Walter *et al.,* 2012) on their part, thereby reducing their net income from production.

Another confrontational situation, regarding the activities of shellfish collectors, is about the periods in which the crabs walk on the surface. This period refers to the time when the crab comes out of his burrow with the goal of mating, thereby becoming an easy target. During this period, according to the local shellfish collectors, crabs being caught by opportunists has become more frequent and intense, which is something that directly affects the supply of the species.

This situation has generated at least two conflicts: firstly for the shellfish collector in terms of the crab closed season, taking into account their need for natural replenishment of wild fauna, and the resulting absence of income due to the fact that there is no unemployment benefit for this species. Secondly, they confirmed the existence of this illegal practice that ends up affecting the reproductive abilities of the species, and consequently, reducing future shellfish supply.

Such a scenario, expressed the contradictions between individual and collective rationality (Cunha, 2004), resembling a social trap, a tragedy of the commons, which can jeopardize this economic activity because of its over-exploitation (Hardin, 1980). In turn, it demands a collective action aimed at the writing and adaptation of common rules that look to encourage cooperation and the sharing of fishing spaces (Sabourin, 2010), thereby allowing local communities to manage the collective resources (Ostrom, 1998).

In the context of local fishermen practices, it is possible to note another conflict that is evidenced by the strong resistance to using safety equipment. It is rare that fishermen consistently use a life-jacket when fishing, for example.

The fishermen justify this non-use of safety equipment by claiming them to be an inconvenience when fishing and, of course, by a certain level of overconfidence. However, to contrast to this situation regarding fishermen, the shellfish collectors are keen to use life jackets as well as other safety gear (pants, hats, gloves and boots) when catching shellfish, thereby evidencing that the search for alternatives and improvements in production processes, the community's women are more receptive and embracive to new ideas (Di Ciommo & Schiavetti, 2012).

3.2.4 Conflict referring to the snook spawning period.

Another noticeable conflict connected to the traditional knowledge of the fisherman, refers to the snook spawning period. According to legislation, ministerial order No. 49, May 13th, 1992 (Ibama, 1992), the closed season for the species happens from May 15th to July 31st, when fishing is banned in coastal and inland waters of the States of Espírito Santo and Bahia.

The local fishermen say that the deadline set by the legislation is too short, as they claim spawning takes place up to September. According to them, this situation can contribute to reduced numbers of the species. Based on this information provided local fishermen, a procedure was adopted to verify the amount of pregnant snook after the period set by the law.

During August and September, every fisherman who landed at the community's moorings with snook had his catch checked to verify if the fish were pregnant. During the eight weeks of the two months under analysis, August and September, it was possible to observe a sample composed of 120 individuals, on average 70% of which were carrying eggs (Figure 4), i.e. during the reproductive period as well as the period when fishing is permitted.

Regulating bodies should pay attention to the importance of the spawning period for this species which, on the one hand, if the period is extended, may demand that more resources be allocated to the unemployment benefit that the fisherman already receive based on the current off-season period, on the other hand, the period in which the species is not be under anthropogenic pressure should be lengthened, thereby allowing the species to replenish itself naturally. It is important to take into account the traditional knowledge of the fisherman, who possess detailed understanding about the local ichthyofauna (Alarcon *et al.,* 2009; Caló *et al.,* 2009; Barbosa Filho *et al.,* 2014; Ferreira *et al.,* 2014) and who have specific knowledge about the sea and the coast (Delicado *et al.,* 2012).

3.2.5 Significance of conflicts observed in the community.

When verifying the importance levels of the conflicts observed in the community, it should be noted that the relationship with amateur anglers, trawling on the beach and the snook off-season period make up the central conflicts in the analyzed community (Figure 5). Since the conflict with amateur anglers is closer to zero and

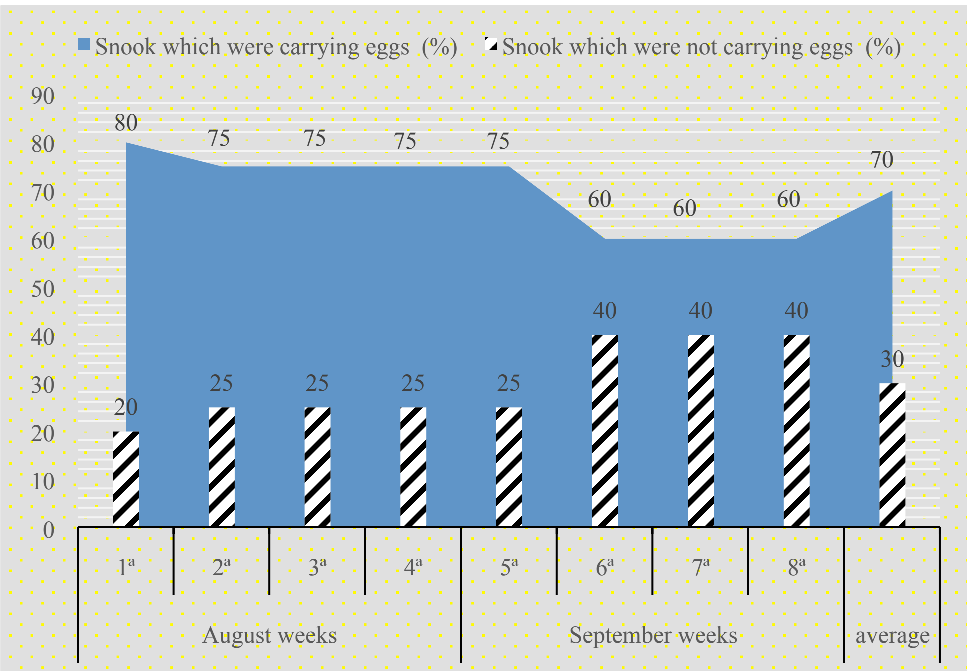

Figure 4. Analysis (%) of the snook caught in August and September, 2013.

Figura 4. Análise (%) dos robalos capturados nos meses de agosto e setembro de 2013.

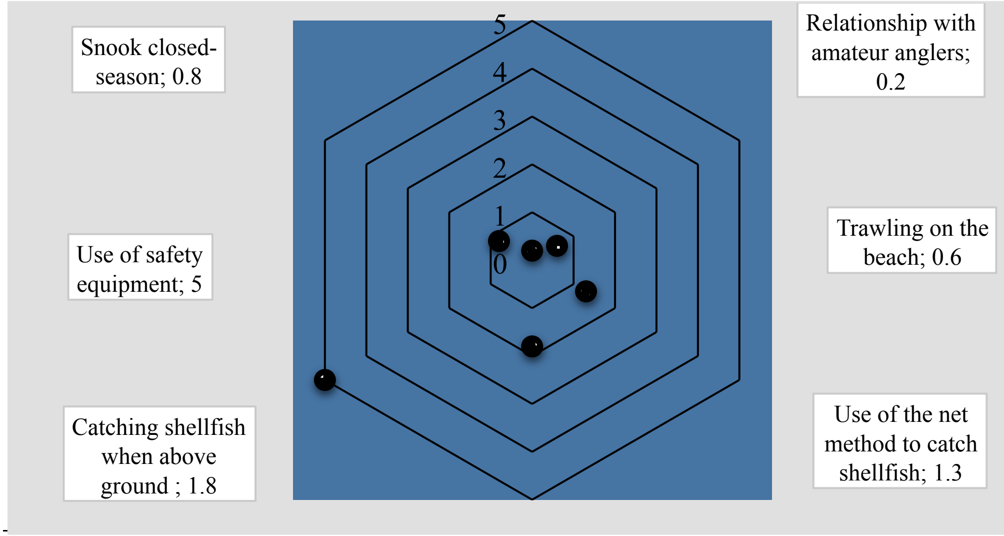

Figure 5. Ranking of the main conflicts observed by fishermen from the ‘Pedras de Una’ community (Bahia).

Figura 5. Ordenação dos principais conflitos observados pelos pescadores da comunidade de Pedras de Una (Bahia).

according to the definition of the constant conflict in Table 2, it impacts greatly on local fishing, with elimination if fish stocks being a possibility.

Identifying of the main conflicts in the community demonstrates the view that the local actors face the most serious aspects regarding the generation of their incomes. This scenario, in which it is possible to create economic losses (Colloca *et al.*, 2004), makes it possible to visualize the interaction between man and nature.

Currently, it is indicated that agents from around the world have been developing management models capable of mediating the conflicting relationship between the extremes. The latter is made up by those who depend on fishing for a living and environmental protection agents, both groups are demanding systemic approaches to fishing management and holistic approaches which consider the interaction between all those involved in fishing activities, this with a view to minimize the negative impacts for stakeholders (Varjopuro *et al.*, 2008).

The ‘Pedras de Una’ community has been looking for solutions to alleviate existing conflicts. The path taken by the community has been dialog with the partner institutions is such a way that together they may effect a greater outcry. Thus, the forums, introductions, meetings of existing councils in the region, and members of the community have worked together to expose the existing difficulties. Another bias, used by the community and also by the institutions from the Canavieiras Resex, is the fact that they are open to scientific research in their area that can contribute to solving the existing difficulties and shortcomings.

In the case of the conflicts that were identified in the ‘Pedras de Una’ community, through action-research it was also possible to observe the actions that were performed and their results (Table 3). The highlight has been the awareness raising and mobilization of the supervisory bodies and researchers to disseminate the local context.

The importance of fishing refers to reflection on aspects of management for its exploitation, both by users and by local authorities, in which there must be integration between regulators of fishing activities in order to develop programs that stimulate fishing in a conscious way (Begossi *et al.*, 2011) and to incorporate local

Table 3 - Conflicts, actions and results observed in the ‘Pedras de Una’ community (Bahia).

Tabela 3 - Conflitos, ações e resultados obtidos na comunidade de Pedras de Una (BA).

Conflicts	Actions to curb the conflicts	Results
Amateur anglers Trawling on the beach Use of the net method to catch shellfish Catching shellfish when above ground Snook closed-season	Awareness raising and mobilization of the supervisory bodies and researchers	Recording in the minutes of meetings of the institutions responsible for supervision; Generation of research and publications in order to disseminate and raise awareness of the competent bodies
Use of safety equipment	Distribution of safety equipment	Use by the shellfish collectors and resistance of the male public.

knowledge in technical solutions (Santos *et al.,* 2012a). In addition, another way to manage fishing activities lies in the empowerment of local actors, primarily through cooperative actions and associations that make it possible for these individuals to effectively participate in decisions, this so as to become part of the organization and the process of fishing regulations in the places where they live (Reis & D'Incao, 2000).

Fishing activities have peculiar characteristics that demand, at certain times, intervention from various professionals in order to regulate their reproduction process. For example, there was regulatory intervention in the State of Virginia (USA), this involved a program that included cooperation between the regulatory agency, commercial fishermen and scientists. In this case, all the parties were looking for a way to provide supplemental income for fishermen and help restore local fishing, which resulted in economic gains, through increased income, as well as environmental gains, through the withdrawal of more than 18,000 pieces of abandoned fishing artifacts that were undermining local fishing (Havens *et al.,* 2011).

Defining parameters in which non-artisanal fishing cannot be practiced is another example of where regulating actors could possibly intervene. This policy could mitigate the conflict of interest and allow artisanal fishermen to enjoy the fruits of what their home environment offers them, as well as being less damaging to the environment, by fishing at smaller proportions and by using equipment that is not excessively sophisticated (Freire & García-allut, 2000; Whitmarsh *et al.,* 2003).

The activities in the analyzed community created the perception that its local development depends a lot more on a dynamic and multidimensional process that involves the community's history, their institutions, their interactions and their ability to build their own destiny, rather than exclusively relying on economic and conservationist aspects (Santos *et al.,* 2012b). Based on this evidence, the local community has sought, via their association, ways to improve the social conditions of the local people through income-generating projects, professional training, partnerships with different institutions and housing improvements for fishermen.

4. Final considerations

Performing education initiatives in the analyzed community assisted in performing the action-research which made it possible to identify the six main existing conflicts regarding fishing in the area: (i) conflict with amateur anglers; (ii) trawl fishing on the beach; (iii) use of the net method for catching shellfish; (iv) catching shellfish when above ground; (v) resistance to using safety equipment; (vi) closed season for snook fishing. It was also possible to verify that the relationship with amateur fishermen has been a quite critical aspect and that, for local fishermen, these amateurs can contribute to local stock depletion due to the practices they have adopted for fishing, thereby placing this conflict at the first level of importance.

As a way to counteract the local conflicts, the fishing community has made partnerships with other similar organizations, universities and public authorities, this in order to understand the necessity and relevance of aligning traditional knowledge, accumulated in the community, with existing knowledge and negotiations among the various partners. However, not all fishermen have the same ability and enthusiasm for the negotiations and clash with the conflicting actors, which ends up resulting in an overlap of responsibilities on a particular group of local actors.

Interaction with the community was also useful, the differences between everyday reality and the information gathered during the first contacts with the community, in which the participatory diagnostics were made, through meetings with the local actors and individual interviews, reinforced the importance of action-research. Another perception, arrived at through the actions developed with the community and captured by action- research, is the responsiveness and commitment of local actors to actions that are designed to emancipate them. For these, they gave time and effort for their implementation, with emphasis on the female audience who have shown themselves to be more dynamic in the search and implementation of new development alternatives.

The fact is that the achievements, obtained by the community through educational initiative projects carried out in partnership with other institutions, has caused the local associative spirit to grow and this, given their dynamics and complexity, has attracted new actors in the development of new relationships of negotiation. One example is the Rede de Mulheres (women's network), which involves all fishing communities in the region and through it, the most diverse social problems are discussed, these range from issues related to marital rights, woman's health, income generation and the paths need to be taken by the traditional fishing communities.

The situation, exposed by daily life in the 'Pedras de Una' Fishing Community, can be represented by the fact that traditional fishing communities need to have a coastal management system that contemplates the man-nature relationship as a way to better use the fishery resources that still exist, while still demanding feedback from authorities that are responsible for inspections regarding the fulfillment of its role. The community believes, as do other fishermen from other communities, that only having the process of awareness regarding fishing limits is not sufficient to, at the minimum, lessen the impacts generated by the conflicts cited throughout this text. It is necessary to adopt punitive and frequent measures against fishermen who do not respect the established limits.

And in this context, the authorities should be working in partnership with local communities in order to have greater powers of action. Local fishermen have knowledge regarding everyday life, boats that fish close to the coast and amateur anglers, they also know about their fellow artisanal fishermen who flout the rules in terms of fishing during the off season and going beyond fishing limits. What is required is political and legal negotiation that would create instruments capable of encouraging talks between the local actors and the supervisory agents.

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