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Environmental zoning and coastal zone conservation: the case of a protected area in Northeastern Brazil*

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ABSTRACT

Conservation of coastal zones is a matter of debate all around the world. In this context, marine protected areas can be counted as legal instruments to ensure proper use of natural resources and promote sustainable development. One of the main aspects for the management of protected areas is environmental zoning. Despite its importance, there are few studies focusing on environmental zoning in semiarid coastal environments. The purpose of this study was to present a case study on environmental zoning of a protected area located in the Environmental Protection Area of the Curú River estuary, which is located on the semiarid coast of the South Atlantic Ocean in Ceará-Brazil. The research was conducted in accordance with the classification criteria used in the Ecological-Economic Zoning (EEZ) of the Coastal Zone, a legal instrument that is important with regards to the Brazilian coast. The work was performed with a GIS technique and involved field activities. The results suggest the following environmental systems within the perimeter of the protected area: river plain, fluvial-marine plain with mangroves, fixed dunes, plain deflation/mobile dunes, plain deflation/fixed dunes, pre-coastal vegetation, and sandspit. The maps of the environmental systems zoning were developed on a 1:40,000 scale and were made to encourage the sustainable use of natural resources. As pressure on the environment by human activities increases, it is essential to update environmental zoning in protected areas, especially in the coastal areas of developing countries.

Keywords: Ecological-Economic Zoning, Coastal Ecosystems, Management, Mangroves.

RESUMO

Zoneamento ambiental e conservação de zonas costeiras: o caso de uma área protegida do Nordeste do Brasil

A conservação da zona costeira é questão de debate em todo o mundo. Neste contexto, as áreas marinhas protegidas na zona costeira estão inseridas como um instrumento legal para garantir o uso adequado dos recursos naturais e promover o desenvolvimento sustentável. Um dos principais aspectos para a gestão das áreas protegidas é o zoneamento ambiental. Apesar disso, existem poucos estudos com foco nos ambientes costeiros semiáridos; sistemas de reconhecida sensibilidade e importância ambiental. Neste trabalho foi realizada a descrição e o zoneamento de unidades geoambientais de uma área protegida na costa semiárida do Atlântico Sul Equatorial (Ceará, Nordeste do Brasil). A pesquisa foi realizada de acordo com critérios de classificação utilizados no Zoneamento Ecológico-Econômico da Zona Costeira; instrumento legal importante no contexto da costa brasileira. O trabalho foi desenvolvido por meio de geoprocessamento e trabalhos de campo que viabilizaram a detecção das seguintes unidades geoambientais dentro do perímetro da área protegida: Planície fluvial; Planície flúvio-marinha

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com manguezais; Dunas fixas; Planície de deflação/dunas móveis; Planície de Deflação/Dunas Fixas, Tabuleiro Pré-Litorâneo e Cordão Litorâneo. Os mapas das unidades geoambientais e do zoneamento ambiental foram desenvolvidos na escala de 1:40.000, sendo feito com o intuito de aconselhar a utilização correta dos recursos naturais, indicando áreas passíveis de uso e subsídios para a gestão ambiental. Considerando o incremento da pressão ambiental por atividades antrópicas, é imprescindível a atualização do zoneamento ambiental nas áreas protegidas, sobretudo nas zonas costeiras dos países em desenvolvimento.

Palavras-chave: Zoneamento Ecológico-Econômico, Ecossistemas Costeiros, Manejo, Manguezal.

1. Introduction

Coastal areas are on the continent/ocean interface and are subject to a number of natural and human-induced pressures (Samaras & Koutitas, 2014; Agostini *et al.*, 2015). The coastal zones that connect terrestrial and marine environments are important for the development of a country in terms of economy, energy, employment, and recreation. Unplanned development coupled with increasing population in coastal zones favors the degradation of these environments (Beeharry *et al.*, 2014).

In recent years, society has become more aware of the degradation levels of coastal and marine ecosystems, motivating studies and proposals for action to halt and reverse the causes, which lead to the environmental compromise of these regions. Although data show that land and ocean areas covered by protected areas have increased rapidly in the past few decades around the world, unfortunately, both terrestrial and marine biodiversity still have experienced rapid declines in that time frame (Mora & Sale, 2011). Protected areas are essential for the conservation of biodiversity and are one of the pillars of virtually all conservation strategies (Agostini *et al.*, 2015).

In this context, the management of coastal/marine protected areas represents one of the main mechanisms for the protection of areas with significant ecological importance, functioning as an essential tool for ensuring the conservation of nature and the promotion of sustainable development (Estima *et al.*, 2014). The zoning is used as a tool for the planning of coastal areas, combining the following characteristics: physical, biological, human, and institutional, along with terrestrial and marine components that can be interpreted and adjusted to the Protected Areas management goals. One of the main features of zoning in coastal areas is that their use must have a social perspective since they are public goods (Rodriguez *et al.*, 2012). There are several methods of zoning of protected areas, including environmental, geoenvironmental, and economic-ecological, but regardless of which one is used, all zoning methods aim for the same result: the delimitation of homogeneous areas (Mcwhinnie *et al.*, 2015). Zoning is undoubtedly the most important process in planning a protected area; it is a key regulatory instrument for the administration and management of ecosystems (Sabatini *et al.*, 2007; Genelitte & Van Duren, 2008).

There is a growing number of studies on the importance and application of zoning for conservation and management of protected areas. As an example, we have the works of Bezaury & Creel (2005), Portman (2007), Grantham *et al*. (2013), and Li *et al*. (2014). In all these works, it was observed that there are still a low number of environmental zoning studies in countries with tropical coasts. The need to update local data to maintain the preservation of those ecosystems arises due to the ecological importance of protected areas in such regions. The purpose of this study was to develop a case study of the environmental zoning of a protected area located on the semiarid coast of the South Atlantic Ocean (Environmental Protection Area of the Curú River estuary). Furthermore, this information is expected to advance the knowledge of environmental zoning in protected areas and provide useful insights for the monitoring and conservation programs of tropical coastal ecosystems.

2. Materials and methods

2.1. Study site

The coastal zone of Brazil is home to 13 of the 27 state capitals and 16 of the 28 Brazilian metropolitan areas and has about 10,800 km of Atlantic coastline, of which 3480 km is in Northeastern Brazil (Schiavetti *et al.*, 2013). The coastal area of Northeastern Brazil extends from the Bay of St. Mark to the Bay of All Saints and has a wide variety of reef ecosystems and estuaries with mangroves (Leão *et al.,* 2010). Control land use and occupation within the Environmental Protection Areas (EPAs) due to inefficient management, either caused by poorly designed or outdated zoning and management plans, and conflicts in socioeconomic interests remain biggest challenges (Schiavetti *et al.*, 2013; Santos & Schiavetti, 2014; Vila-Nova *et al.*, 2014).

The semiarid coastal area is characterized by shallow estuaries, low freshwater inflow, concentrated rainfall in the first half of the year, long periods of drought, and strong salinization as well as by the presence of dunes, sandy beaches, and coastal reefs (Dias *et al*. 2013). The Curú River estuary is located on the semiarid coast of the state of Ceará in Northeastern Brazil (Figure 1). The protected area analyzed in this study is a Marine

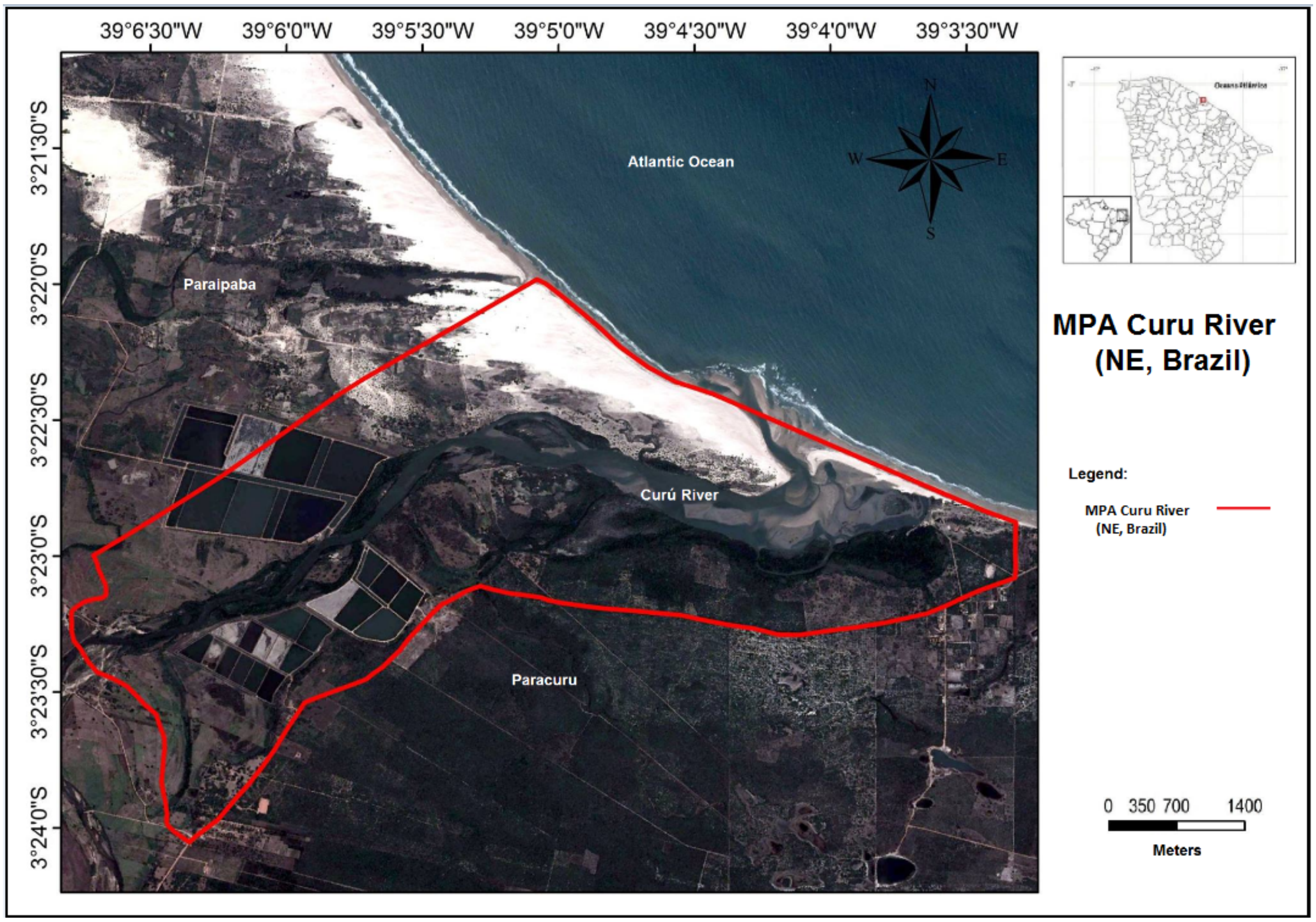

Figure 1 - Marine Protected Area (Environmental Protected Area Curú River).

Figura 1 - Área Marinha Protegida (Área de Proteção Ambiental do Rio Curú).

Protected Area (MPA), known as the Environmental Protection Area of the Curú River estuary, and has a perimeter of 14,979 km and an area of approximately 8.82 km². Within its limits, there exist traditional communities that survive directly from the use of natural resources (fishing and subsistence agriculture). Some of the major environmental problems found in protected areas are the result of human action such as deforestation, agriculture, fishing, fires, and pollution (Gorayeb *et al*., 2005). It is important to study this region to understand how to protect tropical semiarid coastal areas from the intense pressure of urbanization, tourism, and the growth of activities in the industrial complexes and main ports (Pecém and Mucuripe) in the nearby cities (Buruaem *et al*., 2012).

2.2 Methodology

Materials used during this study included: bibliographies, maps, satellite images, articles, books, and government documents relevant to the study area and a geoprocessing tool. The research began with a compilation of data from previous studies of the area (Gorayeb *et al*., 2005; Neto *et al*., 2013). This was followed by the processing of data from geoprocessing activities that were developed through remote sensing image processing (obtained from Google Earth images and Digital Globe 2013) and from the compilation and integration of cartographic material databases. The georeferencing of the satellite data occurred from images of the boundary of the protected area provided by the state entity that manages the protected area (CONPAM). The satellite images allowed the diagnosis of the environmental systems, which refers to the features included in the perimeter of the area.

Additionally, field activities throughout the month of October 2013 were performed and directed by the detailed knowledge of the ecosystems for the identification of the environmental systems. The ecosystems were confirmed and subsequently traced on an image previously georeferenced with a GIS tool, according to recommendations in Santos & Ranieri (2013). The outlines of the receiving units were stained for differentiation and identification only and the sum of the contours of all the environmental systems resulted in a map drawn on a 1:40,000 scale. From the environmental subdivision, zoning of the area for environmental stability/instability was carried out and was defined based on the criteria of environmental elements proposed by the Ecological Economic Zoning (EEZ) of the Ceará Coast (legal instrument) and the methodological proposal of Bertrand (1969). The EEZ and instability/stability of environmental systems were used for determining the priority of the conservation zones.

3. Results and discussion

3.1 Environmental systems

The environmental systems were identified to develop the management plan within the perimeter of the EPA of the Curú River estuary. Seven environmental systems were identified, mapped, and distributed in three macro-areas marked in the EEZ (Figure 2). The order of predominance of the macro-areas, in ascending order, was highlands with 1.27 km²; followed by marine front with 2.09 km², and then fluvial corridor with 5.46 km² (14.40%, 23.70%, and 61.90%, respectively, of the total EPA area). This demonstrates that the estuary is the main element in the landscape of the protected area.

3.1.1 Fluvial corridor

a) Fluvial-marine plain

Predominantly unoccupied, the fluvial-marine plain has some deforestation points with bare soil stains. In this classification, the area devoted to shrimp farming was included, given that the area was occupied previously by a plain tidal river (*Supporting Information I-A*).

The tidal river plain corresponds to the estuary itself. Thus, tidal influence over the river channels facilitates the maintenance of permanently flooded areas with organic rich sediments of continental origin and mangrove vegetation development (Giri *et al*., 2015). Those areas are very unstable, with high vulnerability and sensitivity to occupation and human pressure on natural resources bringing about serious risks for the conservation of such ecosystems (Queiroz *et al*., 2013; Albuquerque *et al*., 2014).

Some factors contribute to the degradation and deforestation of mangrove ecosystems, including the diversion of freshwater flows, deterioration of water quality caused by pollutants and nutrients, aquaculture (Queiroz *et al.,* 2013), mining, and salt extraction. The ecological services of mangroves are extremely important for the ecological balance of coastal areas that were once engaged in protection against floods and hurricanes, reduction of shoreline erosion, and maintenance of biodiversity (Moberg & Ronnback, 2003; Tuan Vo *et al*., 2012). Given the ecological importance and vulnerability of mangroves, there is a clear need for conservation measures for this type of ecosystem. Therefore, these ecosystems are now permanently protected under Brazilian law.

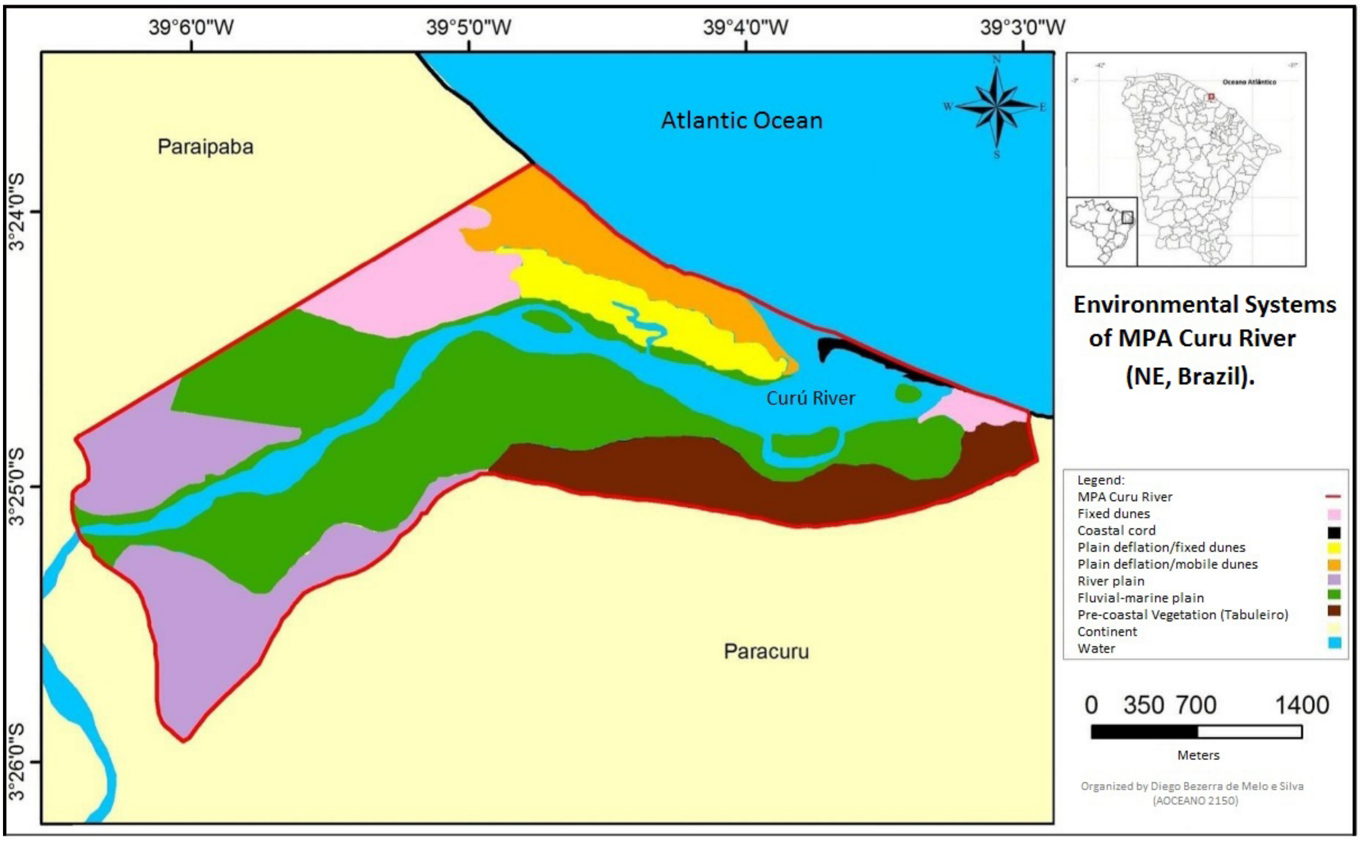

Figure 2 - Environmental Systems (Marine Protected Area Curú River).

Figura 2 - Sistemas Ambientais (Área de Proteção Ambiental do Rio Curú)

b) Fluvial plain

Based on satellite imagery analysis and the EEZ classification criteria, an area was ranked as a fluvial plain when it was not under marine influence. It was possible to identify evidence of a degraded forest with several points of exposed soil stains. Generally, fluvial plain areas have curves of meanders, oxbow lakes, shortcuts, and disruption deposit dikes. However, it was not possible to map those features at the chosen scale. Because the fluvial plain of the Curú River is narrow and extends up to 30 km from the mouth, it is prone to seasonal flooding (overflowing river channel) and is an unstable system with poor support for buildings. Such environmental systems provide relevant ecological contribution to coastal communities and provide surface water reserves for irrigated agriculture in periods of drought and water for livestock and human consumption. In addition, these types of systems present appropriate conditions for recreation and ecotourism. The disposal of contaminants, such as solid waste and other wastes, reinforces the need for protection and remediation measures for the conservation and proper use of these natural resources (Gorayeb *et al*., 2005; Neto *et al*., 2013).

3.1.2 Highlands - Pre-coastal vegetation

Even though the highlands were carved by waterways in the distant past, in recent times they do not get flooded, not even by major storm events. Within this classification, it was possible to identify the pre-coastal tray by bare soil regions, suggesting a forest degradation. There is also evidence of occupation in some areas of the board (livestock and subsistence agriculture, such as sugar cane plantations). Such environmental systems are formed by sediment barriers with vegetation represented by a semi-deciduous vegetation board which is a heavily degraded system (*Supporting Information I-B*).

In terms of human carrying capacity, the pre-coastal vegetation area is the most viable for use and occupation within the EPA, as long as the topography is planed with bands of coalescing alluvial fans, is quite bumpy, and has more stable ground because of a low potential for causing mass movements. Moreover, the pre-coastal vegetation area, cut by the Curú River, creates considerable possibilities for agricultural use, therefore enhancing and protecting the vegetation of the estuarine complex (mangrove and salt marsh ecosystems).

3.1.3 Marine front

a) Fixed coastal dunes

A small area of the EPA, approximately 0.78 km², is composed of only fixed dunes. The dunes, fixed by vegetation, appear isolated from other environmental systems. In the fixed dune feature limit, evidence of marine influence (the appearance of a marine fluvial plain with salt flats of vegetation) at the dune foot was observed (*Supporting Information I-C*).

In Brazil, the dunes (whether mobile or fixed) are protected by law, because of their ecological importance and their special features in semiarid areas. Fixed coastal dunes contain vegetation on sandy quartz sediments with special adaptations to specific environmental conditions (salt water, temperature, and dynamic winds) and have been gaining worldwide recognition for their scientific importance (Tsoar *et al.,* 2009 ; Levin *et al*., 2014).

b) Deflation plain/mobile dunes

The EPA contains two environmental systems (deflation plain and mobile dunes) with different spatial proportions that were not differentiated during the mapping due to scale and geomorphological identification limitations. Nevertheless, there was an advance in knowledge concerning this unit compared to existing literature, especially when compared to surveys of the environmental systems by Neto *et al*. (2013) for the region; this area was defined as a deflation plain, as it was in the EEZ.

Deflation plains are flat or gently sloped surfaces that are found between the maximum tide and the base of the dunes, which usually migrate toward the mainland system (*Supporting Information I-D*). The deflation plains are of great importance for the remobilization and removal of sediment, generating residual accumulation of sediment features and terraces carved by the wind (Farrell *et al*., 2012; Yan & Baas, 2015). Brazil is covered by various ecosystems, including beaches, deflation plains, and dunes, which are a complex endowed with natural features, interdependent and interconnected. However, the current federal environmental legislation of Brazil does not distinguishing the different types of dunes. Federal Law Nº 12.651-2012 (Código Florestal) states that any fixed dune is a feature separated from the others, thus recognizing fixed dunes as Permanent Preservation Areas (PPA). However, excluding the other already mentioned features (such the Deflation plain) of the dune ecosystem (Pinheiro *et al*., 2013).

The dunes have significant ecological value because they contribute to the recharge of the groundwater aquifer and provide a substrate for vegetation and habitat for various animal species. Despite their ecological importance, coastal dune systems are among the most threatened ecosystems in the world, and thereby require conservation efforts and measures to preserve them (Muñoz Vallés & Cambrollé, 2014).

c) Deflation plain/fixed coastal dunes

Although a deflation plain is more likely to be found near the foreshore, specifically in the defined area described in the previous section, fieldwork showed that deflation plains were found near the fixed dunes.

The dunes evaluated in the study area had irregular shapes and were partially or totally obscured by short vegetation. This description suggests that they fall in the hammock classification. In addition, residual features of sediment accumulation were identified around the bushes, so-called rebdous that is characteristic of a deflation plain. In this section of the deflation plain, the presence of features related to wind-preferred corridors (blow-outs) (Farrell *et al*., 2012) were confirmed as being common in vegetated dunes due to the possibility of the stable and unstable morphologies coexisting (*Supporting Information I-E*).

d) Spit

A sandspit (coastal cord) represents the smallest environmental system in the EPA of the Curú River estuary. The barrier spit was identified as a coastal cord because of its elongated sandy feature and the fact that it had been found parallel to the coastline and fused to the mainland at one end (*Supporting Information I-F*).

Concern regarding the interactions of fluvial-wind sediments at various temporal and spatial scales is growing (Han *et al*., 2006). Analyzing satellite images of the study area revealed an increase in the EPA spit of the Curú River estuary over the last 10 years. The coastal cord had increased in length unidirectionally, causing a change in its shape and size.

Those spits are subject to constant morphological changes due to fluvial processes and strong coastal and marine dynamics. In most cases, these dynamics arise either from the inundation of the shoreline by the rising sea level or because of river dams and your consequences (reduction of river flow) (Diena *et al*. 2011). In general, they possess environmental instability, similar to dune environments, because of unconsolidated sandy sediments that can be easily reworked and removed by the action of river water, ocean tides and even the wind itself. However, spits are ecologically important as they act as a substrate for the fixation of mangrove vegetation and are connected to tidal river plains. Thus, they protect the integrity of fragile internal areas as well as provide potential scenic beauty (Otvos, 2000).

3.2 Environmental zoning

The environmental zoning of the protected area was possible after the identified environmental systems were established. The conservation priority areas were distributed as the areas planned for eventual use according to the EEZ and such were described as the following : Special Protection Zone (PZ2); Priority Conservation Zone (CZ1); Special Conservation Zone (CZ2), and Permanent Preservation Area/Zone (PPA or PPZ) (Figure 3 and *Supporting Information II*).

A deflation plain is an area that is found easily in other regions; however, once intensive occupation occurs it may face severe impacts. Therefore, a deflation plain should be in the CZ1 because land occupation is discouraged and activities that are compatible with the capacity of the area are recommended in the CZ1. Nevertheless, there are strong environmental concerns regarding the use and occupation of deflation plains because they are usually associated with dunes, which are in Permanent Protection Areas/Zones (PPA/Z), and thus, protected by Brazilian law.

Both fixed and mobile dunes are protected by Brazilian law and fall under the PPA because of their environmental instability and high susceptibility to negative impacts (such as pollution of soil and water resources). This work was not able to differentiate the dune areas in relation to the deflation plain areas. Research on this in the future is important, especially for environmental licensing purposes within the EPA area. Since the sandspit has similar characteristics as the dunes, it also was classified as a PPA.

The tidal river plain containing mangroves was classified as a PPA as well, due to its particular characteristics that make environmental education and awareness so conveniently recommended. Those areas rich with high ecological potential, biodiversity and production of organic matter and are considerably endangered because of its own fragility, instability, and susceptibility. Moreover, current negative environmental impacts implying extra concerns over the following matters: management and environmental preservation, recovery of degraded parts, and controlled use of resources along those areas.

The fluvial plain is a rare area without much intensive occupation, but even so, it is subject to severe impacts when occupied inappropriately. Therefore, it should be put in the PZ2, which has high standards for the protection and regulation of the land use and occupation since fishing activities are recommended.

The pre-coastal board has the greatest relative environmental stability and, thereby the greatest ability to support human activities. It should be put in the CZ2, where the application of conservation and recovery measures and attempts to reduce the negative impacts are employed.

Day *et al.* (2008) presented a zoning model based on the importance of biodiversity maintenance, ecological health, and ecosystem productivity, which divided the

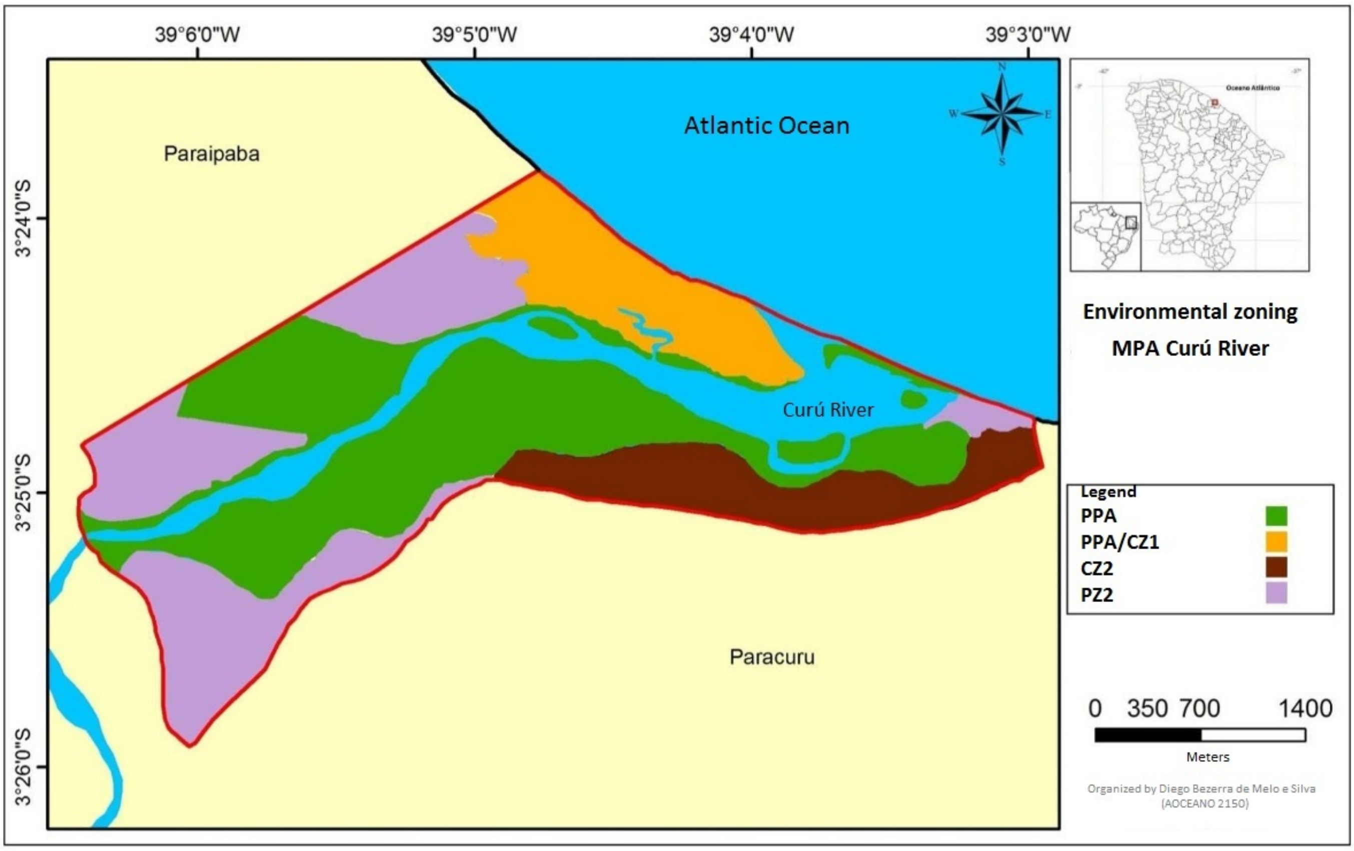

Figure 3 - Environmental Zoning (MPA Curú River).

Figura 3 - Zoneamento Ambiental (Área de Proteção Ambiental do Rio Curú).

areas into four zones. The first zone was ER1, which had the greatest habitat and marine species diversity for both coastal and estuarine environments. The second was the ER2, which had high diversity of habitat and coastal and estuarine marine species. The third was the ER3, which had moderate diversity of coastal and estuarine marine species. The last one was the ER4 zone, which did not have sufficient scientific data yet to classify it.

Genelitte & van Duren (2008) created protected area zones in the Paneveggio Pale di San Martino Natural Park (PPSM), located in the Trentino region of Italy. In their study, the park was divided into three zones. The first one was the A Zone (Integral Reserve), designed to ensure full protection of the environment and ecosystems and minimize the presence or disturbance caused by human activities.

The second one was the B Zone (Guided Reserve) where the cultural, historical, and scenic heritage was protected by restricting the land use to only traditional activities that are not considered harmful to the environment. The third, and last, zone was the C Zone (Controlled Reserve) which aimed to minimize disturbance to the environment as much as possible, but encouraged recreational use and the development of an infrastructure for tourists' facilities.

4. Conclusions

This paper describes the environmental systems of a protected area located on the semiarid coast of Northeastern Brazil and proposes zoning with technical and legal value for conservation purposes. Analysis of remote sensing data, together with fieldwork, seems to be the easiest and most economical way to develop management plans for protected areas on tropical coasts.

Suggested system implementation and periodic update every five years are recommended to, respectively, complete and refine the ecological zoning applied to the protected area analyzed in this article. It would be interesting to develop further the environmental assessment and the determination of vulnerability and support capacity, as well as the details of the dune areas (fixed and mobile) in order to distinguish the deflation plains in semiarid coasts.

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Appendix

Supporting Information associated with this article is available on-line at http://www.aprh.pt/rgci/pdf/rgci-603_Rego_Supporting-Information.pdf

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