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Landscape Geo-Ecology: Guidelines for the Environmental Management of the Estuarine Zones of the Northern Coast of Brazil

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ABSTRACT

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The coastline of Brazil is approximately 7400 km long, and can be divided into two main sectors, the eastern and the northern seaboards. The present geo-ecological study focused on the northern coast, which stretches some 2100 km from the Cape Orange on the frontier with French Guiana to Cape Calcanhar at the northeastern extreme of the country. The aim of this study was a geo-ecological analysis and diagnosis of the estuarine zones of this coast, and the establishment of guidelines for regional planning and municipal management of the coastal fluvial plains and adjoining areas. The principal geo-ecosystemic inter-relationships between the coastal fluvial plains and the surrounding landscape units were also mapped. A diagnostic cartogram was produced in order to establish the problems, limitations, and potential of each geo-ecological unit, as well as to develop management proposals at local and municipal levels, based on geo-ecological criteria, levels of environmental stability, and the intensity of geomorphogenic processes. The results of this study provide potentially important guidelines for the expansion of regional planning strategies in the Amazonian states of Amapá, Pará, and Maranhão, and in Piauí, Ceará, and Rio Grande do Norte in the Brazilian Northeast. The detailed, integrated diagnosis of estuarine zones will also provide a crucial database for the development of long-term master plans for local municipalities.

ADDITIONAL INDEX WORDS: *Coastal management, Thematic mapping, Geoenvironmental Analysis*

INTRODUCTION

The coastline of Brazil has a total length of 7400 km, divided into two main sectors, the eastern and the northern coasts. The present geo-ecological study focused on the northern coast, which stretches 2100 km from the Cape Orange, on the frontier with French Guiana, to Cape Calcanhar at the northeastern tip of the country. A landscape geo-ecology approach was applied to the elaboration of a standardized system of landscape analysis and mapping, with the aim of providing guidelines for the development of an integrated diagnostic tool for the planning of environmental management programs. The definition of geo-ecological units or environments refers to the identification and typing of regional and local landscape features.

From a methodological viewpoint, landscape geo-ecology is based on a dynamic-evolutionary approach, which concentrates on the identification of patterns of territorial development, with the potential for the characterization of the evolution of landscapes, through the analysis of the processes of formation, stabilization, and renovation (Diaknov, 1988). Rodriguez and Silva (2007), classify the ages of landscape components or geocomplexes as young or progressive (which are generally unstable), mature or conservative (relatively stable) and relictual or senile (unstable).

A complementary geo-ecological approach is based on the analysis and classification of anthropogenic or cultural landscapes, which can be divided into natural landscapes (unmodified or reduced impact), anthropogenic/natural (modified or derived), and anthropogenic/technogenic (extensively modified or derived). The combination of these different approaches is essential to the analysis and diagnosis of the northern coast of Brazil, given its diversity and intergradation of landscapes.

Adequate environmental planning is essential for the effective organization of the occupation and preservation of the different landscapes and their corresponding ecosystems. The safeguarding of ecosystem integrity is a fundamental aim of such planning, given the importance of preserving ecological functions and stability for the maintenance of existing landscapes. Territorial organization and planning represent the effective intervention of society, through its public and administrative authorities, with the aim of adjusting the environment of the area to the needs of the social groups that organize it.

According to Rodriguez (2004), environmental and territorial planning may be developed in a variety of ways, based principally on the analysis of geo-environmental and socio-economic conditions. This author refers to two distinct geo-ecological landscape approaches. The first involves pristine or recently-formed environments, such as coral island or newly-formed, as yet unoccupied mobile dunes. This type of scenario is increasingly rare, given the intensity of the occupation of land by present-day societies.

The second approach refers to the analysis and planning of areas that have already been occupied, and have undergone a certain amount of organization as a result of historical, cultural, economic, social, and political factors. In this scenario, the introduction of significant changes in the occupation and use of the land is necessary. Such intervention is necessary to guarantee the most efficient use of natural resources, while at the same time both mitigating environmental degradation and conserving the ecological stability of its natural and cultural systems. The northern coast of Brazil encompasses a considerable diversity of landscapes, some of which are extremely well-preserved, while others present advanced stages of environmental degradation (Figure 1).

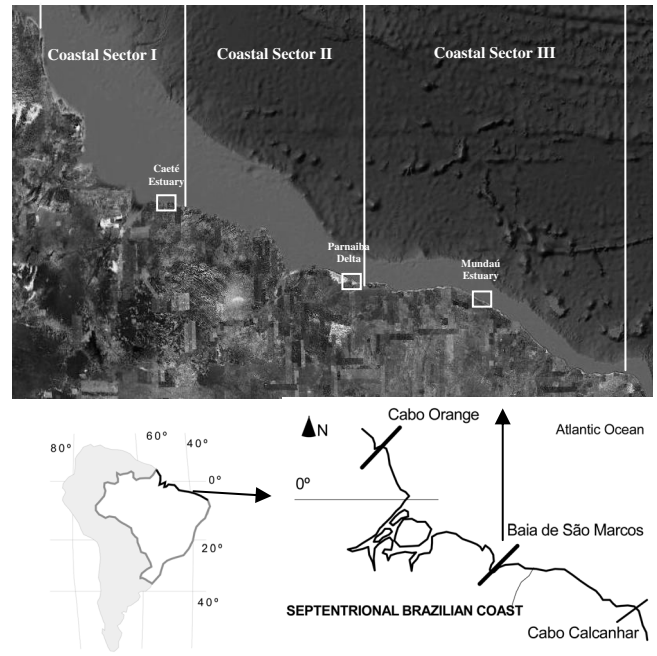


Figure 1. Geographic location of the study areas in northern Brazil.

Rodriguez *et al.* (2007) describe the fundamental aim of environmental planning as the definition of a spatial or territorial model of environmental systems. This spatial model must also include the manifestations and practical conditions of the local political and social organization present in this space, which reflect the occupation, use, and appropriation of its resources.

These authors also affirm that the spatial model depends on socio-environmental factors, such as (i) the structure and function of the natural systems and the potential of the existing environmental resources and services; (ii) the human potential, including the social capital and human resources; (iii) the structure and organization of the system of human settlement, considering both cultural aspects and the historical memory present in the territory; (iv) potential productivity, based on the existing technological infrastructure, the dynamics of the economic sectors, their financial capacity, and access to transportation networks; and (v) the organizational and institutional potential, which is defined by the social capital, the predominant form of social and political organization of the territory, the relationships between institutional bodies, and the social actors and economic agents involved in the management process, considering the levels of social consensus, autonomy, participation, and decentralization.

METHODS

The present study used a geo-ecological approach to analyze and diagnose some of the estuarine zones of the northern coast of Brazil (Figure 1), in order to provide guidelines for regional planning and the municipal management of coastal fluvial plains and their geographic context. The coastline was initially divided into three main sectors on a 1:250,000 scale map of the region, based on the principal regional landscape units (Table 1):

- Sector I: domain of the mangrove forests, between Oiapoque in Amapá and São Marcos Bay in Maranhão (including Pará);
- Sector II: domain of the mangroves and dunes, between São Marcos Bay and the mouth of the Acaraú River in Ceará (including Piauí);
- Sector III: domain of dunes and cliffs, between the mouth of the Acaraú, in Ceará, and Cape Calcanhar in Rio Grande do Norte.

Representative estuaries were selected from each sector for analysis: the Caeté Estuary in Pará from sector I, the Parnaíba Delta between Piauí and Maranhão from sector II, and the estuary of the Mundaú River in Ceará from sector III. The results of the analysis are exemplified in Figure 2.

The coastal fluvial plains analyzed in the present study correspond to the estuarine zones that form where the rivers encounter coastal waters. These areas are dominated by fine sediments and a variety of mangrove soils. Few species of higher plants are able to inhabit these environments, due to the salinity of the soils and the water, the low levels of oxygen in the substrate, and the constant variation in conditions, caused by both tidal flow and seasonal fluctuations in fluvial discharge.

The characteristic ecosystem of the region's coastal fluvial plains is the mangrove, which is made up of three distinct types of habitat – mangrove forests, salt marshes, and salt flats. The region's five mangrove tree species are *Rhizophora mangle* (red mangrove), *Laguncularia racemosa* (white mangrove), *Avicennia germinans* and *A. schaueriana* (black mangrove), and *Conocarpus erecta* (button mangrove). The salt marshes are covered with halophytic grassy-herbaceous vegetation, while the salt flats, which are extremely saline, are not covered in vegetation.

The present study was based on landscape geo-ecology methods, which are based on a systemic approach that includes an integrated analysis of landscape structure (vertical and horizontal), and of the dynamics of its processes (morphogenesis, pedogenesis, and biostabilization), based on criteria of the homogeneity and heterogeneity of landscape typologies.

The study established differentiated scales of analysis and diagnosis, i.e., *1:250,000 for regional, and 1:100,000 for municipal management.* The cartographic data used in these analyses were obtained from exploratory reconnaissance, such as the RADAMBRASIL project, the National Mineral Production Department (DNPM), and the Brazilian Geological Service (CPRM), and topographic maps produced by the Brazilian Army Geographic Department (DSG) and the Northeastern Development Agency (SUDENE). These data were complemented with SPOT and QUICKBIRD satellite images, which were adjusted to the appropriate scales. The interpretation of these images permitted the definition of the regional (coastal fluvial plains, dune fields, and cliffs) and municipal landscape units, such as mangrove forests, salt marshes, salt flats, mobile dunes, inter-dune depressions, live and dead cliffs, and beaches and supralittoral zones.

RESULTS

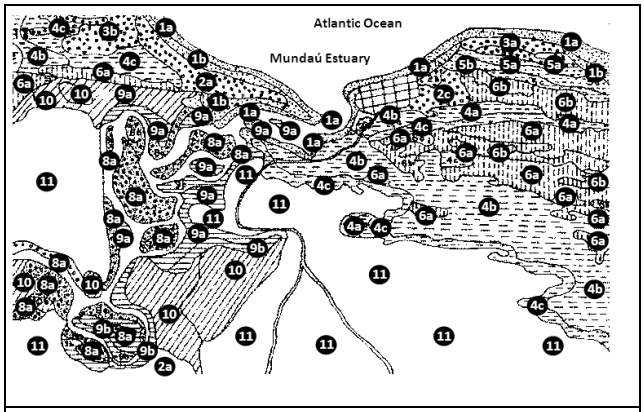
The definition of the geo-ecological units and their cartographic representations was enriched with information on coastal dynamics, such as coastal drift, erosive and depositional processes, levels of environmental stability or instability, forms of land use

and occupation, and the location of risk areas. In addition to a differentiated interpretation of these features, the study analyzed the specific interactions between the coastal fluvial plain and the surrounding geo-ecosystems, and aspects of the dynamics of the landscape, such as the flow of energy and material, processes of morphological evolution, and phytoecological succession.

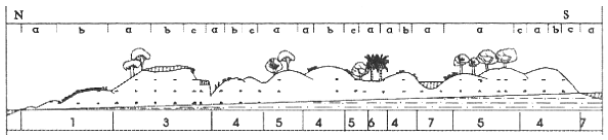
A spatial-temporal analysis was also carried out in order to characterize the level, intensity, and end result of the evolution of the landscapes through geomorphogenic processes. Cartograms and schematic profiles were produced for each of the sample estuaries (sectors I, II, and III), representing its evolutionary processes, vertical and horizontal structures, typologies, and the frequency and intensity of geomorphological and biostabilizing landscape processes. The cartography also represents the principal geo-ecosystemic relationships between the coastal fluvial plains and the surrounding landscape units.

Table 1: Length of the different systems of the geo-ecological sectors of the northern coast of Brazil defined in the present study.

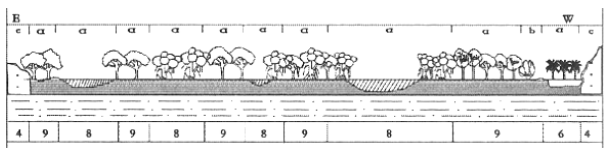
	Coastal sector (km)		
Geo-ecosystem	I	II	III
Coastal fluvial plain	970	57	85
Coastal plain	448	228	312
Total	1418	285	397



Cartogram of the Mundaú Estuary



Profile 1: Dune fields



Profile 2: Mangrove Forest

Legend	
9a	Local geo-ecological feature
9	Geo-ecological sector
a	Geo-ecological subsector

Figure 2. Cartogram and topographic profiles of the Mundaú Estuary.

At the regional level (Table 1), the two principal geo-ecosystems – coastal fluvial plains with mangroves and coastal plains with sandy beaches, tidal plains, dune fields and cliffs – have distinct distributions within the different sectors of the northern Brazilian coast. In sector I, coastal fluvial plain formations dominate, reflecting the humid tropical climate and the perennial river drainage system. By contrast, sectors II and III are characterized by sandy coastal plains, related to the less humid or semi-arid climate.

Analysis of satellite images (Figure 1) indicates that the coastal fluvial plain of the Caeté Estuary (sector I) is at the climax stage, while the Parnaíba Delta (sector II) is under subclimatic stress conditions, and relatively poorly developed. The more detailed analysis of the Mundaú Estuary, which represent sector III (Figure 2), identified and mapped ten distinct sectors and 24 subsectors (Table 2), some of which are shown in profile. The geo-ecological conditions and patterns of occupation and use are discussed below.

DISCUSSION

The results of the present study provide a baseline for the establishment of integrated regional planning strategies for the states of Amapá, Pará, and Maranhão (Amazon region), and Piauí, Ceará, and Rio Grande do Norte (Brazilian Northeast). The results also provide a substantial database for the integrated diagnosis of estuarine zones, which can support the development of municipal master plans.

Macro- and meso-zoning can help define public policies, and the aptitudes and limitations of the occupation and use of the land, based on the geo-ecological zoning of landscapes at the 1:500,000 and 1:250,000 scales. The units defined in the regional macro- and meso-zoning must include the delimitation and effective legal protection of areas of preservation, management, and habitat restoration. The zones destined for specific uses must also be defined, taking into account the natural aptitude of the areas, and federal and state economic policies and guidelines.

On a local and municipal scale, it is possible to develop stimulatory policies, municipal master plans (through 1:100,000 and 1:50,000 scale analyses), and community management strategies (1:10,000 and 1:5000 scales). These initiatives should include the political, economic, cultural, and environmental strategies necessary for sustainable development at the municipal and local levels.

In their overview of the landscape geo-ecological approach Rodriguez *et al.* (2010) identified six principal territorial aspects of the analysis: (i) identification of the aptitudes and limitations of the different potential land uses and exploitation of natural resources, and definition of the general possibilities and limitations for the spatial organization of the territory; (ii) definition of the elements that enhance or limit the efficiency of the exploitation of natural resources; (iii) identification of the processes that degrade or may deteriorate local environments; (iv) definition of the environmental status of the different landscape units that compose the territory; (v) verification of the influence of the structure and function of natural systems on the physical space and the location of socio-economic patterns and infrastructure; (vi) identification of the perception, valorization, inter-relationship, and coexistence of local social groups with the natural environment.

From the perspective of Richling (1994) and Rodriguez (2004), environmental planning is characterized by its integrative approach, in the principles of territorial differentiation and integration, dynamics and functionality, social participation, and, ultimately, the institutional capacity for environmental management. Geo-ecological analysis provides guidelines for environmental zoning and subsequent planning and territorial management, based on the differentiation, classification, and mapping of geo-ecological landscape units. The cartographic interpretation can be conducted at different scales, providing information not only on natural geographic landscapes, but also the transformations provoked by the development of the cultural landscape.

In this context, the production of a map of the geo-ecological units of the landscape does not simply contemplate the physical-geographic features, but also the social construct of the human intervention into natural systems. The cartographic material presented here represents part of the results of the integrated analyses of the estuarine systems of the northern coast of Brazil. It is hoped that these analyses will provide a database for the systematic development of planning and management strategies on regional and municipal scales.

CONCLUSIONS

Environmental planning and management are radically different from the traditional or conventional forms of spatial organization. They are thus conceived as essential tools for the development of measures for the integrated management of territories and their specific array of landscapes. In particular, environmental planning based on a geo-ecological diagnosis is integrating, systemic, multi-optional, and probabilistic.

Estuarine zones are intensely dynamic, and this is reflected in the interaction among the different processes and geo-ecological components that compose the different features of the landscape of these environments and the surrounding coastal systems. Given the continental dimensions of its coastline, and the intensifying occupation of its physical spaces, Brazil is in urgent need of systematic planning with regard to the occupation, preservation, and conservation management of its coastal ecosystems, and in particular its estuarine zones, which are among the most important areas from both economic and ecological perspectives.

The Federal University of Ceará, in partnership with other universities and research institutions from the Amazon region and the Brazilian Northeast, has developed a series of research projects in the different sectors of the northern coast of Brazil, that have formed the basis of numerous graduates theses. These initiatives have also benefitted from an international collaboration and exchange program with the Geography Department of La Habana University, which has been supported by CAPES/MES-Cuba and the Brazilian National Research Council (CNPq). The swapping of experiences has resulted in a more refined application of the landscape geo-ecology approach in the development of analyses, diagnoses, planning, and the management of coastal territories on the northern coast of Brazil.

Table 2: Key to the cartogram of the Mundaú Estuary (Figure 2).

Locality: *Coastal plain (beach, supralittoral zone, marine terrace and dune field)*	
Sector	**Subsector**
1. Beach and supralittoral zone with psammophilous pioneer vegetation on quartzose marine sands.	a) Beach with algae, mollusks and small crustaceans. b) Supralittoral zone with *Ipomoea pescaprea*, *Remirea maritima*, *Paspalum maritimum* and *Panicum vaginatum*.
2. Marine terrace (coastal community) with coconut plantations and psammophilous pioneer vegetation on quartzose marine sands.	a) Higher sandy terrain occupied by private residences. b) Lower, seasonally-flooded terrain occupied by grazing activities. c) Sandy terrain recently formed by deposits of sand.
3. Eolianitic dunes with shrubby psammophilous pioneer vegetation on quartzose marine sands.	a) Windward slope with *Remirea maritima*, *Conocarpus erecta*, *Bysonima* spp. and *Chysobalanus icaco*. b) Summit with concretions of silica and calcium carbonate, and no vegetation. c) Leeward slope with *Byrsonima* spp. and *Anacardium occidentale.*
4. Mobile dunes with psammophilous pioneer vegetation on quartzose marine sands.	a) Windward slope with *Remirea maritima* and *Cyperus* sp. b) Summit covered with vegetation and highly mobile sediments. c) Leeward slope with no vegetation and highly mobile sediments.
5. Fixed dunes with subperennial shrubby vegetation and trees on quartzose sands with humic horizon.	a) Windward slope covered with bushes, *Byrsonima* spp. and *Chrysobalanus icaco*. b) Summit covered with bushy vegetation, including *Anacardium microcarpum* and *Byrsonima* spp. c) Leeward slope with tree species such as *Anacardium occidentale* and *Hymenea courbaril*.
6. Interdunal depressions with coconut plantations and grassy-herbaceous vegetation on quartzose sands with humic horizon.	a) Higher sandy terrain with plantations of coconut and cashew. b) Lower, seasonally-flooded sandy terrain

	covered with *Cyperus* sp. and *Xyris* sp., used for grazing.
7. Perennial lake with sub-perennial bushy riverside vegetation on hydromophic quartzose sands and alluvial soils.	a) Perennial lake bordered by *Hymenea courbaril*, *Anacardium occidentale* and amphibious and aquatic plant species.

Locality:
Coastal fluvial plain

Sector	Subsector
8. Permanently-flooded area and river margins with perennial mangrove vegetation on hydromorphic solodized organic soils.	a) Permanently flooded river margins, with *Rhizophora mangle* and watercourses. b) Higher parts of the fluvial plain. c) Lower terrain with formation of microlakes and salt flats.
9. Seasonally-flooded area with perennial mangrove vegetation on hydromorphic gley soils.	a) Lino-clayey terrain with *Avicennia* spp. and *Laguncularia racemosa*. b) Sandy-clayey terrain with *Conocarpus erecta*.
10. Low terrace at the edge of the dunes with halophytic-hygrophilic vegetation on solonetzic solonochack soil (salt marsh).	a) Sandy-clayey terrain covered with *Xyris* sp. b) Sandy-clayey terrain covered with *Batis maritima*.

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