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Characterisation of mangrove forest types in view of conservation and management: a review of mangals at the Cananéia region, São Paulo State, Brazil

M. Cunha-Lignon†‡∞ , C. Coelho Jr. ‡*, R. Almeida‡α, R.P. Menghini‡π, Y. Schaeffer-Novelli‡, G. Cintrónβ and F. Dahdouh-Guebas£

† National Institute for Space Research - INPE, São José dos Campos (SP), 12227-010, Brazil marilia@dsr.inpe.br

β U.S. Fish and Wildlife Service, Arlington, 22203-162, United States of America, gil_cintron@fws.gov

‡ Instituto BiomaBrasil - IBB, Recife, 52041-050, Brazil, {marilia.cunha, clemente.coelhojr, renato.almeida, ricardo.menghini, yara.novelli}@biomabrasil.org

∞ Université Libre de Bruxelles - ULB, Brussels, 1050, Belgium {marilia.cunha, fdahdouh}@ulb.ac.be

£ Vrije Universiteit Brussels – VUB, Brussels, 1050, Belgium, fdahdouh@vub.ac.be

* Universidade de Pernambuco – UPE, Recife (PE), 52041-050, Brazil

α Universidade Federal do Recôncavo Baiano - UFRB 44380-000, Cruz das Almas (BA), Brazil

π Universidade Paulista – UNIP, 05347-020, São Paulo (SP), Brazil

ABSTRACT

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Wetlands, including mangroves, perform diverse functions, besides the production of goods and services on an ecosystem and landscape scale. The combination of functions, goods and ecological services has a fundamental importance for society. The study of physiographic types is intended to help in dealing with and understanding the function of a complex system. Complex systems are those that share four attributes: diversity of constituents, interdependence between parts, connectedness and adaptation. This study was carried out in the Cananéia region, located in the southern coast of the São Paulo State (25^{o}S), Brazil. Data from the 1980's to 2009 on the structural development of mangrove forests of two physiographic types, fringe and basin, were analyzed to discern patterns of spatial and structural organization. The fringe forests studied in the region presented a predominance of *Rhizophora mangle* and high structural development due to the high inundation frequency in depositionally stable sites. Fringe forests, located in progradation areas with low tidal energy, were dominated by *Laguncularia racemosa* with low structural development. The basin forests are dominated by *R. mangle* or *L. racemosa,* presenting reduced structural development in function of the lower inundation frequency, a predominantly sandy substrate and low salinity. But some basin forests dominated by *Avicennia schaueriana* were better developed reflecting the growth characteristic of this species. The results shown here highlight the large variations in the quality and intensity of forcing functions and the structural and functional diversity allowed by the plasticity of the species involved and their capacity to interact and adjust to the environment in which they develop.

ADITIONAL INDEX WORDS: ***dynamics, self-organisation, management***

INTRODUCTION

Mangrove forests once covered more than 200,000 km^2 of sheltered tropical and subtropical coastlines. They are disappearing worldwide at 1 to 2% per year, a rate greater than or equal to declines in adjacent coral reefs or tropical rainforests. Losses are occurring in almost every country that has mangroves, and rates are rising more rapidly in developing countries, where more than 90% of the world's mangroves are located (Duke *et al.*, 2007).

Mangroves perform several functions such as inundation control, protection from erosion, storm, floods, and wave damage, recreation and tourism, and generate tangible goods such as fish and shellfish and forest products. They possess distinct ecological attributes at multiple levels of organization such as site or stand, ecosystem and landscape levels (Schaeffer-Novelli *et al.*, 2005).

Management decisions are normally taken based on inadequate or poor information or incomplete or distorted perspectives that fail to acknowledge or grasp the complexity and extent of the system (Schaeffer-Novelli *et al.*, 2008). Coastal and marine research and conservation needs to be more holistic and dynamic than terrestrial management because of the greater openness of these ecosystems, the nature of the embedding matrix and the multiplicity of cross scale linkages between the objects embedded in it (*e.g.* Dahdouh-Guebas and Koedam, 2008). Management for resilience and monitoring becomes essential in mangrove area management (Schaeffer-Novelli *et al.*, 2008).

An analysis of mangrove forests must take into consideration the hydrological energy regime of a coast, the first step for understanding its functional and structural responses when facing environment, stress and management changes (Lugo *et al*., 1990; Bosire *et al.*, 2008). The source of environmental energy determines the characteristics of the ecosystem, its distribution and form being defined by the spatial distribution of this energy (Lugo *et al*., 1990). Subsidiary energies (non solar) possesses diverse essence and quality, which are not readily comparable (Lugo *et al*., 1990). However maximum utilization of the energies available comes from the interaction of these different quality energies so that they amplify each other (Odum, 1983). Lugo and Snedaker (1974) presented a physiographic classification of mangrove forests (fringe, riverine, basin, overwash, scrub, and hammocks), assuming that each type reflects the energy sources and quality spectra of a given place. In fact the energy of sunlight is a multiple source described by its spectrum and includes visible and photosynthetically active light as well as heat.

Cintrón *et al*. (1985) suggested that this classification could be reduced to three broad types (fringe, riverine and basin). Overwash mangroves were considered to be basically self-enveloping fringes, whereas scrub and hammocks were considered to be special types of basins. Fringe forests are located at the edges of water bodies (estuaries and bays) and are frequently flooded by tides. Riverine forests are located at the edges of rivers. Whereas basin forests occur in inland areas that are less frequently flooded by tides and where an accumulation of organic matter and anoxia can be found in the sediment.

Schaeffer-Novelli *et al*. (2000) suggested only two physiographic types (fringe and basin), considering the riverine type as a fringe. The main criteria used to describe these major types are water movement and the hydroperiod in a system. Fringes and riverine forests are considered flowing water systems. Basins are still-water systems. Riverine stands are considered a type of fringe; its structural attributes are derived from the particular setting they occupy (where lower salinities and high nutrient levels prevail).

The study of the physiographic types helps in the understanding of the great variability and complexity of structural and functional development, as a result of the response of mangrove plant species to abiotic factors (Schaeffer- Novelli *et al*. 1990a).

Based on the physiographic classification of mangrove forests and the energy signature concept, the objective of this work is to help to understand mangrove dynamics and give a contribution to the conservation and management of the Cananéia region (State of São Paulo, Brazil).

Study Area

The mangrove distribution and theirs characteristics along the Brazilian coast is profoundly influenced by coastal types and process scales (Schaeffer-Novelli *et al*., 2000). Schaeffer-Novelli *et al*. (1990a) proposed a division of the Brazilian coast into eight segments (I-VIII) where similar environmental conditions, geomorphologic processes, disturbance regimes and landscape mosaics predominate.

The study area is situated in the Cananéia-Iguape Coastal System (Figure 1), localized in segment VII (Schaeffer-Novelli *et al*., 1990a), along the southern tract of the coast of São Paulo State, (SE Brazil), at 25°S. The region is characterized by a wide coastal plain, with an approximate area of 2,500 km^2, bordered on the northeast and southwest by beach ridges. The average annual temperature of Cananéia is 21.4°C, with a mean annual rainfall of 2,270mm (Schaeffer-Novelli *et al.*, 1990b). In this area the tide is of the mixed type, with a mean height of 0.81m. The Iguape River is the largest freshwater input of the region.

Mangroves colonise practically the entire coastal system dominated by quaternary sediments. The region can be considered as being reasonably well conserved from the point of view of human interference. Next to agriculture and tourism, activities linked to fishing are the principal economic activities of the local community (Grasso and Schaeffer-Novelli, 1999).

METHODS

Data from 1980's to 2009 on the structural and functional characteristics of the mangrove forests of Cananéia region were analyzed in terms of the different physiographic types, complemented by recent field observation.

Information on the region presented by Adaime (1985), Peria *et al*. (1990), Menezes (1994), Coelho-Jr. (1998) and Cunha-Lignon *et al*. (2009) were obtained according to the same methodology (Cintrón and Schaeffer-Novelli, 1984), thus enabling comparison with their results.

Regression equations were calculated using tree diameter and density values of plots representing mangrove forests in progradation areas, fringe and basins types, from Coelho-Jr. (1998) and Cunha-Lignon *et al*. (2009).

RESULTS AND DISCUSSION

The results reflect the great structural and spatial variability that exists in the Cananéia mangrove geomorphic setting (Figure 2).This structural variability reflects the diversity of environments and depositional facies within the setting and the different intensities of subsidiary energies (hydrodynamic forces acting on the system (Table 1). Changes in hydrology and water quality are important indicators, as change in these parameters can influence colonization, succession and zonation and in time can cause increased tree mortality and consequent alteration of the structural characteristics of the stand and eventual changes in depositional

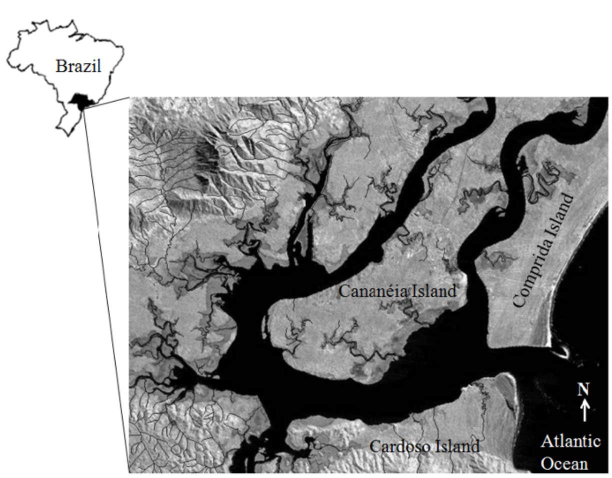

Figure 1. The study area, the Cananéia region, located on the southern coast of São Paulo State, Brazil.

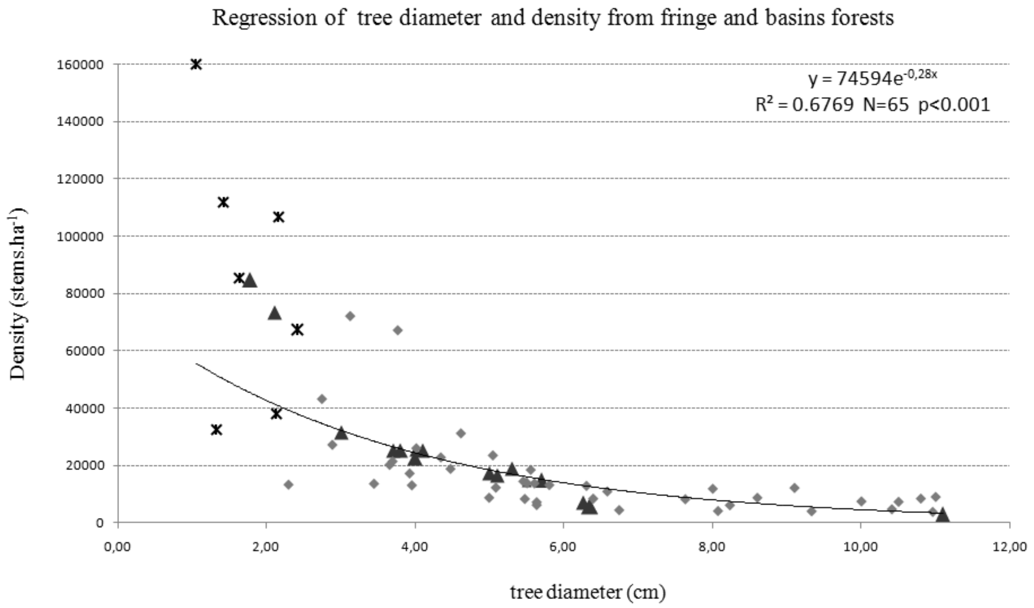

Figure 2. Regression of tree diameter and density from fringe and basin forests, from Coelho-Jr (1998) and Cunha-Lignon *et al*. (2009). Fringe forests are located in progradation areas (stars) and depositionally stable sites (diamonds). Basin forests are indicated by triangles. The equation, correlation and significance coefficients (R^2 and p-value) are given.

and erosional rates (Lugo *et al.*, 1990) that impair sediment transport or increase wave scour.

In the **fringe forests** of the region studied by Adaime (1985, 1987) and Coelho-Jr (1998), *Rhizophora mangle* L. (Rhizophoraceae) attains great structural development (Figure 2), due to frequent flooding and varying exposure to the effects of river, wave and tidal processes.

Fringe forests, located in progradation areas with low tidal energy, were dominated by *Laguncularia racemosa* (L.) Gaertn. F. (Combretaceae) with low structural development and high density (Figure 2), and were associated to the smooth cordgrass *Spartina alterniflora* Loiseleur (Poaceae) (Cunha Lignon *et al.*, 2009).

The **basin forests** studied in Coelho-Jr (1998) were found to be dominated by *R. mangle*, presenting reduced structural development and low density due to the low inundation frequency, predominantly sandy sediment, and low salinity values (Figure 2). However, sites studied by Adaime (1985) and Cunha-Lignon *et al.* (2009) proved to be well developed due to the dominance and structural characteristics of (*Avicennia schaueriana* Stapf. & Leechman (Acanthaceae), (Figure 2), which occupied areas with more uniform physical-chemical characteristics and energy flow. In the Cananéia region, some of the **basin forests** are associated with the rear part of the mangroves, next to the *restingas*, separated by a narrow transition zone, occupied by Cyperaceae, as well as *Hibiscus pernambucensis* Arruda, *Acrosthicum aureum* L., *Annona glabra* L. and *Dalbergia ecastophyllum* (L.) Taub. Some basin forests present similar characteristics to fringe forests in accretion areas, with high density and low tree diameter (Figure 2). The stability of each site should be the main responsible to differences between forest types.

Based on distinct physiographic types and vegetation characteristics, submitted to different subsidiary energy, we proposed some strategies to manage mangrove forests of Cananéia region (Table 1).

The destruction of this part of the forest by reclamation for real state causes significant changes in hydrological conditions and consequently in forest dynamics, forcing alteration in zonation patterns, besides the loss of primary productivity (Brown, 1990) and spatial diversity, and effects on carbon dynamics (Bouillon *et al.*, 2004; Bosire *et al.*, 2005).

Hydrological and tidal flows are considered as a crucial source of subsidiary energy in wetlands (Lugo *et al*., 1990). In general, the mangrove forests of the Cananéia region are strongly coupled and influenced by hydrological processes such as frequent flooding by freshwater or tidal energy. Mangrove development here reflects the diversity of depositional settings within a transgressive barrier island estuarine-lagoonal system where these flows produces a diversity of tide dominated morphologies that become the template for mangrove colonization. This depositional system is characterized by the diversity of morphological units, their interconnectedness and interdependence, dynamism and adaptive open-endedness. The system self-assembles, and recognition of this has important implications for management.

Human activities which directly affect fringe forests, by eliminating plant cover and extraction of mangrove products, can reduce. Requisite variety and overcome the carrying capacity of the ecosystem leading to environmental degradation (Lugo *et al.*, 1990) or chronically reduce its robustness leading to cryptic ecological degradation (Dahdouh-Guebas *et al.*, 2005), which in turn may affect mangrove functionality (Dahdouh-Guebas & Koedam, 2008) particularly its capacity to recover from external disturbances.

Iftekhar and Saenger (2008) analyzed the vegetation dynamic in the Bangladesh Sundarbans mangroves reviewing forest inventories from 1926 to 1997, the authors encountered limitations arising from the need to compare information obtained using different methodologies and different measurements of the same parameters. This was not the case in the present study which compared observations and above-ground structure and forest architecture measurements from 1980's using the same methodology, which allowed a good quality comparison.

Table 1: Physiographic types, its characteristics, subsidiary energy and proposed to management. (1) Coelho-Jr (1998); (2) Adaime (1987); (3) Peria *et al*. (1990); (4) Menezes (1994); and (5) Cunha-Lignon *et al*. (2009)

Physiographic types	Vegetation characteristics	Subsidiary energy	Monitoring and management
Fringe	**In stable sites** (1, 2, 3, 4) Dominance of *R. mangle* High structural development	High inundation frequency	Monitoring of hydrology and water quality Elimination of tension points
	In progradation sites (5) Dominance of *L. racemosa* Low structural development		Monitoring of responses to impacts
	Dominance of *R. mangle* (1) or *L. racemosa* (1) Reduced structural development (1)	Low inundation frequency sandy sediment Low salinity values	
Basin	Most of the basin forests are associated with the posterior part of the mangroves, facing the *restingas* (1)		Maintenance of spatial and structural arrangement
	Dominance of *A. schaueriana* (2, 5) High structural development (2, 5)	Areas with more uniform physico-chemical characteristics and energy flow	

Mangroves are highly resilient and flexible systems, adapting themselves to a wide range of environmental conditions. This characteristic makes the management of this system simpler, being limited to the conservation of the properties and processes that control them (Cintrón-Molero and Schaeffer-Novelli, 1992).

Mangroves have played a vital role in the development of the Latin American and Caribbean countries and their value increases as tropical countries develop and ecological values are increasingly recognized (Lugo, 2002). Effective governance structures, socioeconomic risk policies, and education strategies are needed now to enable societies around the world to reverse the trend of mangrove loss and ensure that future generations enjoy the ecosystem services provided by such valuable natural ecosystems (Duke *et al*., 2007).

Technical information *per se* does not represent the total of necessary subsidies for the conservation of complex coastal ecosystems, such as mangroves. Government institutions should contribute with the implementation of environmental awareness programs and integrated coastal management planning. Local governments often possess detailed information on the necessities and problems of the coastal zone communities, pointing out conflicts and limits that could affect certain decisions. Unfortunately the people most familiar with natural systems are not usually in powerful positions and are not consulted by those who are. The groups of coastal enterprises besides local communities should be supported at all governmental levels (Cicin-Sain and Knecht, 1998).

CONCLUSION

Structural and functional variability observed in mangrove ecosystems of the Cananéia region (SE Brazil) are determined by the plasticity of the species involved and by the capacity of self-adjustment to the diverse energy signatures.

The state of mangrove conservation in the Cananéia region, as well as the large volume of technical information accumulated over the past decades of research made it possible to examine ecological processes, assisting in the conservation and management of this valuable ecosystem.

Technical information, government support and information of local communities should be worked over together, being essential for the implementation of integrated coastal management programs. It is possible to manage mangrove areas considering the opportunities for the recreation, tourism, fishing, education and research which they offer, without requiring much manipulation of the system, and conserving the material and nutrient (energy) flow which sustains its production and control the water quality.

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