Anais XIII Simpósio Brasileiro de Sensoriamento Remoto, Florianópolis, Brasil, 21-26 abril 2007, INPE, p. 4331-4338.

Selecting suitable sites for red mangrove restoration using GIS and geoprocessing

Arimatéa de Carvalho Ximenes [1]
Philip Conrad Scott [2]

[1]Departamento de Processamento Digital de Imagens - DPI
Instituto Nacional de Pesquisas Espaciais (INPE) – São José dos Campos, SP.
arimatea@dpi.inpe.br

[2] Instituto de Ciências biológicas e Ambientais - ICBA
Universidade Santa Úrsula (USU) - Rio de Janeiro, RJ.
philip@usu.br

Abstract. Due to the increased awareness of the importance of mangroves world-wide, restoration methods are being studied. Itaipu lagoon, RJ, Brazil, was drastically altered with a permanent break-water connection established in 1979. Since then, a daily tidal regime was established and the lagoon's margins became likely places for mangrove colonization. The aim of this study was to select areas around the Itaipu lagoon perimeter more likely to successfully harbour red mangrove (*Rhizophora mangle*) propagules for new colonization and development of a man-made mangrove. For this, environmental data were collected and integrated in a GIS, within a model contemplating known ecological requirements for red mangrove. A total suitable area of 6.12 hectares was found, where 15.300 *Rhizophora* propagules could be planted using a 2 x 2 meter grid spacing.

Key-words: *Rhizophora mangle*, mangrove, environmental restoration, GIS, Brazil, Itaipu, manguezal, restauração ambiental, SIG, Brasil, Itaipu.

1. Introduction

Mangroves exist in coastal ecosystems in a transitional environment between land and marine, characteristic of tropical regions subject to the action of tides. It is constituted of woody tree species and many micro and macroalgae adapted to fluctuations in water salinity, shifting sediments with low levels of oxygen (Chapman, 1976; Cunha-Lignon, 2001) and naturally occur in the intertidal zones of estuaries (Tomlinson, 1986).

In Brazil, mangroves are present along more or less continuously from the extreme north beginning at Oiapoque river in Amapá (4^{o}N) to Santa Clara, in Santa Catarina (28^{o}S) (Cintrón and Schaeffer-Novelli, 1983). The presence of various limiting factors and their fluctuations characteristic of marginal environments determine strong selective pressure over individuals of various species. This fact determines the low biodiversity of such ecosystems because few species can tolerate extremes of temperature, water salinity, winds, solar radiation, dryness, inundation, among other factors (Vannucci, 2001).

Accordingly, mangrove vegetation has adapted and presents unique morphological and physiological characteristics such as peculiar ramifications and root systems (Vannucci, 2001). Strategic adaptive adaptations include viviparity (Chapman, 1976; Tomlinson, 1986; Schaeffer-Novelli, 1995; Vannucci, 2001), resistance of propagules to water salinity and tide fluctuations (Rabinowitz, 1978; Schaeffer-Novelli, 1995; Twilley, 1998; Vannucci, 2001).

Mangroves are known to be important biomass producers and exporters to the estuary and nearby coastal environments (Dahdouh-Guebas et al. 2000). They provide protection and refuge for juvenile fish as the structural complexity renders difficult the action of several types of piscivores (Laegdsgaard and Johnson, 2001). They are important in increasing fishery production on the coastline. For these and other reasons, they exert an important socio-economical role (Dahdouh-Guebas et al., 2000).

This study aimed at developing a GIS supported method for the selection of suitable areas successful planting of new man-made red mangrove (*Rhizophora mangle*) areas on the perimeter of a natural coastal lagoon. The study should be able not only to select those areas, but also quantify them for use in future estimates of natural productivity enhancement subsequent to red mangrove establishment.

2. Materials and Methods

2. Study area

Itaipu lagoon is situated in Niterói, state of Rio de Janeiro, Brazil (Fig. 1), between longitudes 43°06' and 43º02'W and 22°58' and 22°56'S. It is part of the Piratininga-Itaipu lagoon system. Local climate is classified as type Aw, according to Köppen, with a rainy season in the summer and a dry winter. Average annual temperature is 24^{o} C. Annual precipitation is ca. 1300mm (Barroso et al. 1994). Itaipu is a 2 Km^2 largely circular with an average 1.2m depth. It receives waters from a 23 Km^2 watershed (Knoppers et al. 1999) via the João Mendes, Vala, Valão de Itacoatiara rivers. Its main freshwater contributor is the João Mendes river with 0.10 m^3s^{-1} from a 16.8 km^2 watershed (Knoppers et al. 1999).

Up to the 1970s Itaipu had occasional exchange with the coastal sea via a natural canal opened during heavy rainfalls, whence water accumulated in Itaipu lagoon and high tide conditions contributed to bursting of the separating beach sandbar. (Lavenère-Wanderley and Silva, 2000). In 1979 a 15 wide canal was opened and a breakwater was built to ensure permanent communication (FEEMA, 1988). Since then, the arrival of halophytes has occurred naturally. Patches of mangroves have been established on the western flank of the lagoon. Since 2000, a local NGO has attempted to plant red mangrove propagules on the southwestern flank. (Fonseca and Drummond, 2003).

The northeastern flank of the lagoon is characterized as being rather flat and accumulating fine sediments mostly clay and rich in humic and organic soils (ECP, 1979; IBAMA, 1998; Barroso et al. 1994). After the canal was established and a permanent connection with the sea was established, Itaipu had the beginnings of the necessary conditions to harbour proper mangrove such as brackish water and reducing soils.

2.1 Images and maps

The main software used in this study was IDRISI 32, developed by Clark University, USA. The file which was used as the base for all studies was an aerial photograph (scale 1:8000) (**Figure 1**), supplied by Fundação CIDE (1996) and scanned using an EPSON ACTION II scanner. The image was subsequently georeferenced using the RESAMPLE module of IDRISI. To achieve this, ten ground control points (GCP) were obtained using a Garmin III Plus during a field trip. Another 20 GCPs were acquired from local admiralty chart of Baía de Guanabara. The aerial photo was georeferenced to UTM projection coordinates.

Field trips were carried out in order to obtain first hand knowledge on the local environment and vegetation coverage types. The aerial photograph was important in assisting identification of geophysical aspects such as the intertidal zone, vegetation cover including existing mangrove patches, sand dunes, and urban areas along the lagoon's perimeter.

2.2 Sampling

Three environmental variables were selected: sediment type (particle size), soil organic matter content and interstitial water salinity. Values for these factors were obtained from 18 sampling stations established with a GPS on the intertidal zone of the lagoon perimeter. (**Figure 1**). The samples were collected and placed in plastic bags kept refrigerated until arrival at the Universidade Santa Úrsula's Chemical Oceanography lab. These were analysed for particle size, and organic matter content according to the method described in Suguio

(1973). Interstitial water samples were also collected at the same stations according to the method described in Shaeffer-Novelli and Cintrón, (1986). For this, holes 30 cm deep were excavated, and once the interstitial water filled the hole, water samples were collected and salinity measured in situ with a portable Bio-Marine Aquafauna salinity refractometer with a ± 1 psu accuracy. All data for this study was obtained between October 2000 and October 2001.

2.3 Site selection criteria

The criteria chosen for selecting areas suitable for planting of *R. mangle* were defined after a careful review of the literature describing red mangrove site characteristics (**Table 1**). The parameters chosen were: particle size, organic matter content, and salinity of the interstitial water. Red mangroves are well adapted to grow in rich, saline soils with very fine sediment particles.

Table 1 – Environmental parameter ranges typical of red mangrove sites.

Parameters	Range	Refererences
SEDIMENT PARTICLE SIZE	< 0.125mm	Carmo, 1998; Cintrón and Schaeffer-Novelli, 1983; Louro et al.; 1994; Chen and Twilley, 1998.
SOIL ORGANIC MATTER CONTENT	> 10%	Carmo, 1998; Cintrón and Schaeffer-Novelli, 1983; Louro et al. 1994; Twilley et al. 1995; Tomlinson, 1986.
INTERSITIAL WATER SALINITY	>25 < 55 psu	Soto and Jimenéz, 1982; Cintrón and Schaeffer-Novelli, 1983; Schaeffer-Novelli, 1995; Chen and Twilley, 1998; McKee, 1993b apud: Chen and Twilley, 1998.

Additionally, red mangroves are usually restricted to the intertidal zone (Chapman, 1976; Pool et al. 1977; Rabinowitz, 1978; Soto and Jiménez, 1982; Tomlinson, 1986; Mckee, 1993b apud: Chen and Twilley, 1998; Schaeffer-Novelli, 1995; Soares, 1999; Cunha-Lignon, 2001; Moscatelli, 2003).

2.4 Particle size

Particle size depends on particle type. Red mangrove will grow under variable soil compositions, but Carmo et al. (1998) concluded that *R. mangle* is better adapted to fine sediments such as predominate in sandy-clayey soils, especially those with higher concentrations of clay. In Ilha do Cardoso, SP, healthy red mangrove stands can be found in places where soil type is composed predominantely of silt and clay particles. These sites also had the best conditions for underground plant development and plant biomass (Louro et al. 1994, Cintrón and Schaffer-Novelli, 1983). As such, for the criterion particle a cut-off point of <0.125mm which includes clay to fine sand was established for areas to be considered for planting of red mangrove propagules.

2.5 Organic matter content

Usually, red mangrove stands grow in soils with higher organic matter content than other mangrove species forming stands (Cintrón and Schaffer-Novelli, 1983; Carmo, 1998; Louro et al. 1994; Twilley et al. 1995). Bearing in mid that on the basis of the definition of degraded areas, such as predominant around Itaipu lagoon, where environmental changes may be so profound that hardly the environment would be able to replace losses of organic matter, (Brown and Lugo, 1994), the criterion 'organic matter content' cut off level was set to < 10%.

This would allow for areas with relatively low organic matter content to be considered for mangrove planting.

2.6 Interstitial water salinity

The great influence that soil salinity has over physiological processes in mangrove trees has been discussed by Soto and Jiménez (1982). Cintrón and Schaffer-Novelli (1983) have shown that high salinity can limit biomass accumulation, with significant reduction over 55 psu. Lugo and Snedaker (1974) found best development conditions for mangrove forests in the Caribean and Gulf of Mexico where salinity is close to that of seawater, i.e. 35 psu. In Caribean islands, negative effects on mangrove structure were found in areas where salinity exceeded 50 psu. In Puerto Rico a relation of increasing salinity gradient and decline of mangrove structure was found (Cintrón et al. 1978 apud: Twilley, 1998). The same was reported for Costa Rica by Soto and Jiménez (1982).

The consequence of increasing salinity and its stress on plants is the inhibition of root growth and dwarfism (Larcher, 2000). According to Chen and Twilley (1998) *R. mangle* would be the species most sensitive to high salinity when compared to *Laguncularia sp.* and *Avicennia sp* the growth of its propagules inhibited between 45 a 60 PSU with a maximum tolerance at 70 psu. However, lower salinities can favour the settling of competitive species which do not tolerate saline stress (Moscatelli, 2003).

3. Development of the thematic layers of the model

The model structure used in this research was simple and did not weigh differently the three thematic layers developed particle size (**Figure 2**), organic matter content (**Figure 3**),and interstitial water salinity (**Figure 4**). One constraint layer was used which incorporated exclusion of areas already occupied by existing mangroves, as well as all areas outside intertidal flats.

Each of the thematic layers was developed by interpolating the values found for particle size, organic matter content and salinity, over the total surface. Subsequently, all values outside the intertidal zone were excluded using overlay with a mask. The resulting images were then reclassified according to **Table 2**. A final overlay operation was carried out where Suitable areas were identified by multiplying all the suitable areas of each environmental factor considered where:

*Suitable areas = (Suitable particle_Size * Suitable_Organic * Suitable_Salinity) * (Intertidal_Areas * No_Mangroves)*

Table 2 - Ranges for environmental variables found in the study area and reclassification criteria used.

Particle size (µm)	Aggregate name (Wentworth Classification)	Organic mater Content (%)	Salinity (PSU)
3.90 – 62.5	* Silt/Clay	1 – 5	1- 15
62.5 – 125	* Very fine sand	* 5 – 10	* 15 – 25
125 – 250	Fine sand	* 10 – 15	* 25 – 35
250 – 500	Medium sand	* 15 – 20	35 – 45
		* 20 – 25	45 – 55
		* 25 – 30	55 – 66

4. Results and Discussion

The results of the model where suitable areas were found in intertidal areas devoid of mangrove vegetation where sediment particle size, organic matter content and interstitial water salinity were within the reclassified limits determined based on the available literature are illustrated in **Figure 5**. All small pixel groups found (< 0.08ha) were ignored from the final suitability map. The suitability selection model developed in this study, found a total suitable area of 6.12 hectares on intertidal flats on the lagoon perimeter. In this area, using a 2 x 2 meter grid spacing, 15,300 red mangrove propagules could be planted. This is roughly 21% of the total area intertidal area analysed. The suitable areas found were grouped into seven semi-isolated continuous patches. The suitable patches were re-classified in three size classes i.e. small (0.08 – 0.20ha); medium (between 0.21 – 0.40ha) and large (> 0.4ha) (**Table 3**). The two largest areas consisted mostly of very fine sand, salinity between 25-45psu and between 10-20%.

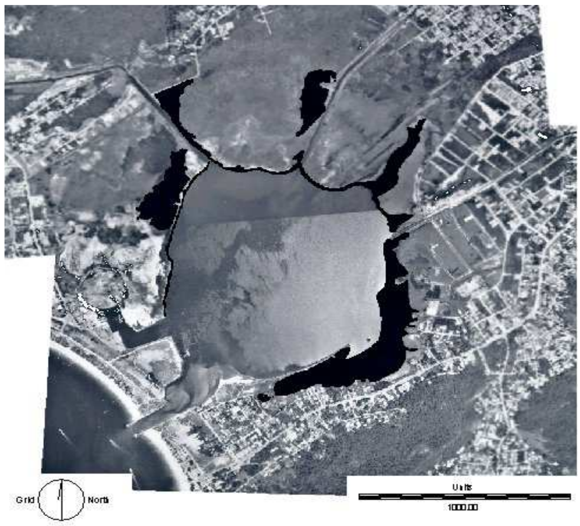

Figure 1 – Intertidal zone in black

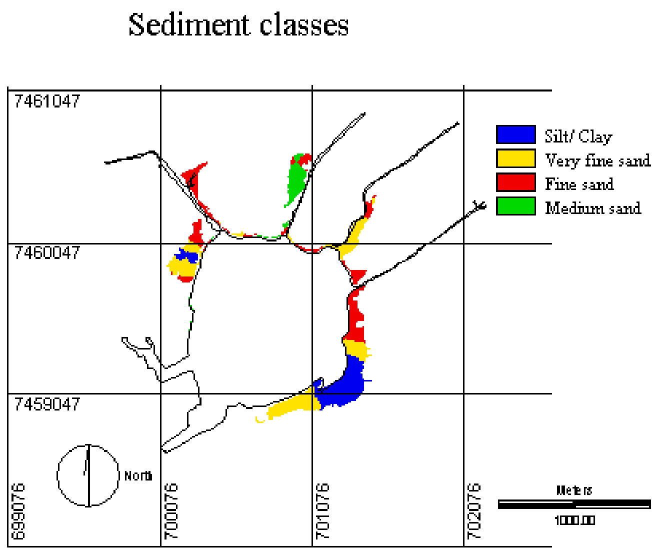

Figure 2 - Sediment types

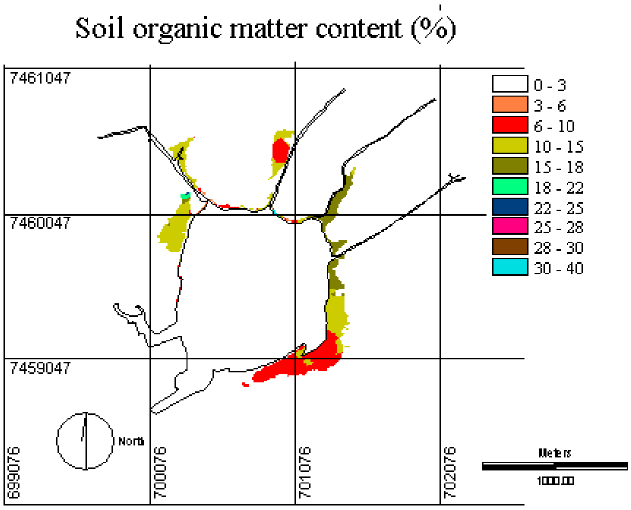

Figure 3 – Organic matter content

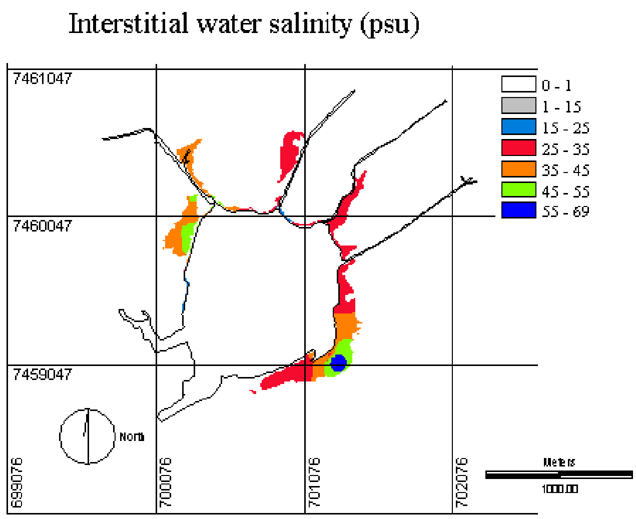

Figure 4 Interstitial water salinity

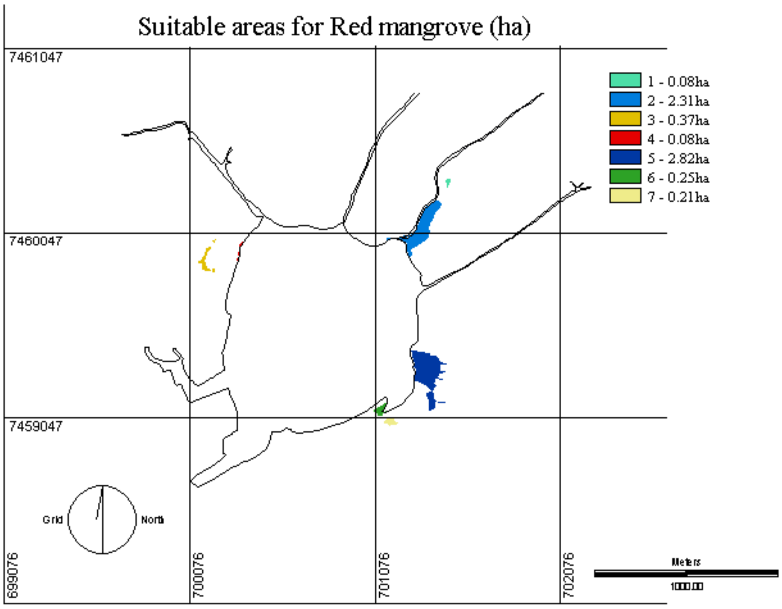

Figura 5 – Suitable areas for Red mangrove

Table 3 - Areas suitable for red mangrove planting and number of propagules and approximate costs.

Classes	Area ID	Size (Ha)	Propagules needed (spacing 2x2m)	Planting cost (US$)
Large (> 0.4ha)	5	2.82	7,050	5,929.91
	2	2.31	5,775	4,857.48
Medium (0.20 – 0.4ha)	3	0.37	925	778.04
	6	0.25	625	525.70
	7	0.21	525	441.59
Small (<0.08 – 0.20ha)	1	0.08	200	168.22
	4	0.08	200	168.22
Total	**7**	**6.12**	**15.300**	**12,869.16**

Using Moscatelli's costing figure for mangrove planting (US$ 2,102.80/ha, pers. communication) under ideal conditions, i.e. absence of soil contaminants or solid residues, relative ease of access throughout terrain, and ready availability of Rhizophora propagules, it would take approximately 20 days with 5 men and one supervisor to conclude the task. That the estimated cost for planting red mangrove in the whole area would amount to US$ 12,869.

5. Conclusions

The model developed generalized spatial information from limited field survey stations over a one-year period in order to obtain thematic maps describing the local environmental parameters for red mangrove growth in a coastal area. The predictions made by the model could not be properly validated as such would demand resources not available. However, given the limitations imposed by time and resources, it must be said that two significant coincidences did occur.

1. Small (< 1ha) already existing local mangroves patches existing on the western side of the lagoon, did fall into the predicted areas. 2. A community-based mangrove planting project pioneered by a local NGO (APREC), and based on the intuitive experience of its members, chose another area also predicted by the model for planting red mangrove propagules (eastern

side of the lagoon). This patch has been developing since approximately the year 1999 to present.

The exercise was useful in obtaining approximate figures and setting baseline environmental information on red mangrove requirements in a GIS-based model which can be used for finding areas of highest success probability in mangrove restoration projects. The implications include quick and fairly reliable estimation of cost and number of propagules needed for such projects.

References

Barroso, L.V., Silva, L.F.F.; Knoppers, B. A. Diagnóstico ambiental do sistema lagunar de Piratininga/Itaipu, Niterói, RJ. In: Simpósio de Ecossistemas da Costa Brasileira: subsídios a um gerenciamento ambiental, 3., 1994, São Paulo, **Anais**.... São Paulo: ACIESP, 1994. Artigos, p. 189-195.

Brown, S. and Lugo, A. E. Rehabilitation of tropical lands: a key to sustaining development. **Restoration Ecology**, v. 2, n. 2, p. 97-111, 1994.

Carmo, T. M. S.; Almeida, R.; Oliveira, A. R.; Xavier, S. Z. Caracterização de um trecho do manguezal do rio da Passagem, Baía de Vitória, Vitória-ES, Brasil. In: Simpósio de Ecossistemas Brasileiros. 4, 1998, São Paulo. **Anais**... São Paulo, 1998. Artigos, p. 06- 16.

Chapman, V. J. **Mangrove vegetation**. Valduz, Cramer, 1976. 447 p.

Chen, R.; Twilley, R. R. A gap dynamic model of mangrove forest development along gradients of soil salinity and nutrient resources. **Journal of Ecology**, v. 86, p. 37-51, 1998.

Cintrón, G.; Schaeffer-Novelli, Y. **Introduccion a la ecologia del manglar**. Montevidéu, Unesco/Rostlac, 1983. 109 p.

Cunha-Lignon, M. **Dinâmica do manguezal no sistema de Cananéia-Iguape, Estado de São Paulo - Brasil**. 2001. 72p. Dissertação (Mestrado em Oceanografia) – Universidade de São Paulo, São Paulo. 2001.

Dahdouh-Guebas, F; Mathenge, C.; Kairo, J. G.; Koedan, N. Utilization of mangrove wood produts around Mid Creek (Kenya) among subsistence and commercial users. **Economic Botany**, v. 54, p. 513-527, 2000.

ECP – ENGENHEIROS CONSULTORES PROJETISTAS S/A. **RIMA – Relatório de influência sobre o meio ambiente**: Plano estrutural de Itaipu. Rio de Janeiro. 1979. 347 p.

FEEMA. **Relatório de Avaliação das condições físico-químico do sistema lagunar Itaipu/Piratininga**. Rio de Janeiro, DEP/DIAG, 1988. 8 p.

Fonseca, S. M.; Drummond, J. A. Reflorestamento de manguezais e o valor de resgate para o seqüestro de carbono atmosférico. **História, Ciências, Saúde –Manguinhos**, v. 103, p.1071-1081, 2003.

IBAMA. 1998. **Caracterização ambiental da lagoa de Itaipu**. Rio de Janeiro, Parecer Técnico N^o 61/98 Processo N^o 02022.2885/08-01.

Kairo, J.G.; Dahdouh-Guebas, F.; Bosire, J.; Koedam, N. Restoration and management of mangrove systems – a lesson for and from the East African region. **South African Journal of Botany**, v. 67, p. 383-389, 2001.

Knoppers, B.; Carmouze, J.P.; Moreira, P.F. Nutrient dynamics, metabolism and eutrophication of lagoons along the east Fluminense coast, state of Rio de Janeiro, Brazil. In: **Environmental geochemistry of coastal lagoons systems of Rio de Janeiro**, Brazil. Knoppers, B. A., Bidone, E. D., Abrão, J. J. (Eds.). Rio de Janeiro, Niterói, UFF/Programa de Geoquímica Ambiental, FINEP. 1999. 210 p.

Larcher, W. **Ecofisiologia vegetal**. São Carlos, São Paulo: RiMa, 2000. 531p.

Laegdsgaard, P.; Johnson, C. Why do juvenile fish utilise mangrove habitats? **Journal of Experimental Marine Biology and Ecology**, v. 257, p. 229–253, 2001.

Lavenère-Wanderley, A. A. C.; Silva, M. A. M. Intervenções antropogênicas no ecossistema lagunar de Itaipu - Niterói - RJ. In: Simpósio de Ecossistemas Brasileiros: conservação, 5., 2000, Espírito Santo. **Anais**... São Paulo: ACIESP, 2000. Artigos, p. 120 -137.

Louro, I. A.; Gomes, M. L.; Schaeffer-Novelli, Y. Biomassa subterrânea em um bosque de mangue na Ilha do Cardoso, Cananéia, Estado de São Paulo. In: Simpósio de Ecossistemas da Costa Brasileira: subsídios a um gerenciamento ambiental, 3., 1994, São Paulo. **Anais**... São Paulo: ACIESP, 1994. Artigos, p. 135-140.

Moscatelli, M. Tirando o pé da lama. Rio de Janeiro, **Ciência Hoje**, v. 32, n. 191, p. 48-49, 2003.

Pool, D.; Snedaker, S.C.; Lugo, A. E. Structure of mangrove forests in Florida, Puerto Rico, Mexico and Costa Rica. **Biotropica**, v. 9, n. 3, p. 195-212, 1977.

Rabinowitz, D. Early growth of mangrove seedlings in Panama, and an hypothesis concerning the relationship of dispersal and zonation. **Journal of Biogeography**, v. 5, p. 113-33, 1978.

Schaeffer-Novelli, Y.; Cintrón-Molero, G. **Guia para estudo em área de manguezal**: estrutura, função e floral. São Paulo: Caribbean Ecological Research, 1986. 150 p.

Schaeffer-Novelli, Y. **Manguezal***:* ecossistema entre terra e o mar. São Paulo: Caribbean Ecological Research, 1995. 62 p.

Soares, M. L. G., Estrutura vegetal e grau de perturbação dos manguezais da Lagoa da Tijuca, Rio de Janeiro, RJ, Brasil. **Revista Brasileira de Biologia**, v. *59*, n. 3, p. 503-515. 1999.

Soto, R.; Jiménez, J. A. Análisis fisonómico estructural del manglar de Puerto Soley, La Cruz, Guanacaste, Costa Rica. **Revista de Biologia Tropical**, v. 30, n. 2, p. 161-168, 1982.

Suguio, K. **Introdução à sedimentologia**. São Paulo: Edgar Blucher/EDUSP, 1973. 317 p.

Tomlinson, P.B. **The Botany of Mangroves**. Cambridge: Cambridge University, 1986. 419 p.

Twilley, R. R.; Snedaker, S. C.; Yáñez-Arancibia, A.; Medina, E. Mangrove systems. In: Heywood, V.H. (Ed.). **Global biodiversity assessment**. Biodiversity and ecosystem function: ecosystem analyses. Cambridge: Cambridge University, 387-393. 1995.

Twilley, R. R. Mangrove wetlands. In: Messina, M. G., Conner, W. H. (Ed.). **Southern Forested Wetlands**: ecology and management. Florida, Lewis, 1998. 445-473 p.

Vannucci, M. What is so special about mangroves? **Brazilian Journal of Biology**, v. *61*, n.4, p. 599-603, 2001.