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Maintenance of Mangrove Forests through the Conservation of Coastal Ecosystems

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ABSTRACT

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In coastal regions, the synergism among different ecosystems enables the development of unique landscapes presenting characteristics that reflect the water input and dynamics. The estuarine complex of Caravelas, south of Bahia (Brazil), represents an example of this interaction. This tide dominated estuary is associated to important areas of "*Restinga*" communities (vegetation growing on sandy coastal plains), where several freshwater springs occur. This study characterizes the structure of mangrove forests and discusses its relationship with freshwater dynamics at the estuarine system. At the river mouth we observed mixed forests of *Rhizophora mangle* and *Avicennia schaueriana,* with high structural development (mean height of 8.2 m and relative basal area dominated by trunks higher than 10 cm). At the intermediate segment of the river, the forests are represented only by individuals of *R. mangle* with branched live trunks and many dead trunks (mean diameter at breast height - $\overline{DBH}$ - of 3.3 cm and mean height of 4.4 m), reflecting water and saline stresses. The forests at the upper segment are dominated by *Laguncularia racemosa* with mean DBH of 6.7 cm and mean height of 4.4 m. Species distribution and structural development are not only related to the river's salinity gradient but also to the input of freshwater from the springs in the "*Restinga*" area. We concluded that the conservation of the "*Restinga*" vegetation and consequently the maintenance of freshwater sources are vital for the functioning and maintenance of all ecosystems in the landscape, guaranteeing their goods and services and consequent human well-being.

ADITIONAL INDEX WORDS: *watershed, connectivity, landscape ecology*

INTRODUCTION

Guaranteeing habitat connectivity among habitats is currently the most efficient way of preservation and maintenance of the landscape. This conception provides an integration of the acting processes, including the interactions among continental, coastal and marine areas through their bodies of water. The interactions among environments create different ecological niches favoring the maintenance of a high biological diversity.

Regional geological changes that took place in the Quaternary defined, along the Brazilian coast, countless structural characteristics and spatial arrangements among marine and terrestrial ecosystems, connected by drainage basins. At this scale, mountains function as topographical diffusers responsible for draining and conducting rainwater, resulting in a classical model of springs, streams and rivers that flow into estuarine areas or directly into the sea. However, in some coastal plains such as Caravelas in the south of Bahia, sandy plains perform this role in a local scale. These morphologic units, originated in the last sea transgression (about 5100 years b.p.-; SUGUIO *et al.*, 1985), are responsible for the capture, storage and conduction of rain waters. The *Restinga* vegetation strengthens this characteristic acting in the storage and maintenance of water, besides other ecosystem functions, such as sand ridge fixation and coastal protection from wind and wave energy (PEREIRA, 1998; SILVA, 2002; SANTOS, 2001), promoting the stabilization of the entire system. Another ubiquitous type of vegetation is the mangrove, distributed throughout the entire estuary from the town of Caravelas to Nova Viçosa. This ecosystem also perform important roles in the stabilization of the system, protecting the shoreline from erosion and silting up (MAZDA *et al.*, 1997; UNEP-WCMC, 2006). Besides the former functions, mangroves act in the maintenance of high biological productivity and diversity in the adjacent estuary (EWEL *et al.*, 1998).

This study aims to present the structural variability of mangrove forests located along an estuarine gradient at the Caravelas-Nova Viçosa system, using it as an example of the integration among different coastal ecosystems. We propose a conceptual model of connectivity between habitats through the hidryc bodies.

The present study is part of the technical report required during the process of creation of the Cassurubá Extractivist Reserve. In Brazil, the National System of Conservation Units, which includes the Extractivists Reserves, accomplishes the commitments arising from the country's signature and ratification of the Convention on Biological Diversity.

METHODS

The Caravelas estuary is located in the southernmost part of the state of Bahia, Brazil (Figure 1). According to LEIPE *et al.* (1999) this estuary behaves as a typical tide dominated estuary. Seven main rivers flow into this estuary: Macaco, Massangano, Jaburuna, Cupido, do Poço, do Largo, Caribê and Peroba. This region presents extremely fragile ecosystems such as mangroves, *Restingas* and marshes, among others. The Abrolhos Reef

Complex, the largest coral reef in the Western South Atlantic Ocean, with 60,000 km² (ANDRADE and DOMINGUEZ, 2002), is located in the adjacent coastal zone between 20 and 70 km from the shoreline.

In the region of the Macaco river a detailed survey was carried out to enable the analysis of the relationships among marine influences, freshwater input from springs and structural characteristics of mangrove forests. These relationships were evaluated through the analysis of structural variability (species composition and structural development) and of the salinity of the groundwater in twelve stations located along river. These stations were numbered upstream.

The methodology for the characterization of the forest structure of mangroves is presented, in a general form, by CINTRON and SCHAEFFER-NOVELLI (1984). In each station a plot was delimited in accordance with forest density, so as to sample a representative number of individuals, as well as forest homogeneity in terms of structural characteristics (species composition and structural development of individuals). After the plots had been delimited all the individuals taller than 1m were identified according to their species and their height was measured. The diameter at breast height (DBH) was also measured and each individual was classified as alive or dead. In each sampling station, the mean height of the forests, the $\overline{DBH}$ (mean diameter at breast height), the basal area and the basal area contribution (%) of dead and live trunks were calculated by species and by DBH classes (< 10.0 cm and > 10.0 cm).

The salinity values of the groundwater were obtained through five holes dug in each forest structure characterization station at various depths in accordance with the observation of the interstitial water level.

The results discussion was based on the social-economic and environmental report presented by Soares (2006). This author identified and described in detail the phytophysiognomies and features present in the region, including freshwater sources. This discussion, alongside consolidated concepts in the world literature, was the basis for the conceptual model of functioning and interaction among the systems identified in the landscape studied was proposed.

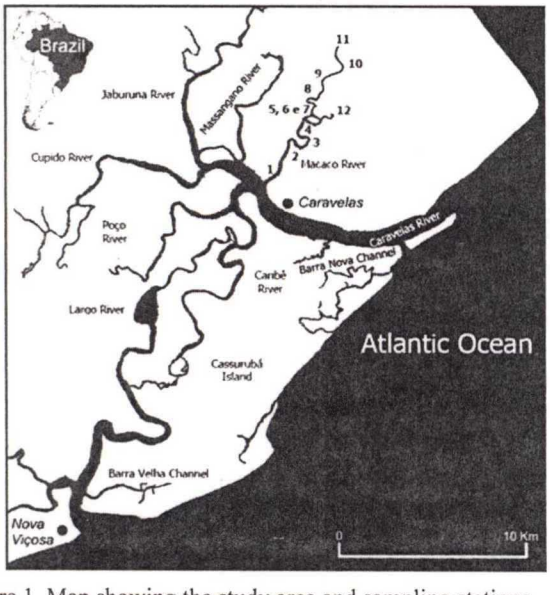

Figure 1. Map showing the study area and sampling stations.

RESULTS AND DISCUSSION

All along the Macaco River we observe a high structural diversity of mangrove forests. In this river it is evident the control of salinity of interstitial water through the balance between the input of water of continental origin and the saltwater input by tides, on the characteristics of mangrove forests.

The results shown in Figure 2 demonstrated, in the stations closer to the Macaco River estuary (stations 1 and 2), interstitial salinity varying from 35 to 40 ‰ with the formation of well developed mixed *Rhizophora mangle* and *Avicennia schaueriana* forests, with basal area contribution concentrated in trunks with $\overline{DBH}$ slightly above 10 cm and mean height between 6.7 and 8.2 m.

In the intermediate section of the river, stations 3 and 4, with salinity between 28.3 and 31.7 ‰, there is a change to monospecific *R. mangle* communities. However, a high contribution in basal area of dead trunks is observed, particularly in station 3, besides large gaps and a twisted architecture which imply a drastic reduction in basal area.

Stations 5 to 10, located more upstream, with salinity between 19.7 and 29.37 ‰, are also characterized by monospecific forests of *R. mangle*. However, they have a percentage in basal area of live trunks above 85%. In station 10 there is an optimal salinity condition for the development of *R. mangle* in the Macaco River, and this stretch presents the maximum values of mean height, $\overline{DBH}$ and contribution in basal area of trunks with DBH higher than 10 cm among this river's stations.

The Figure 3 shows an example of an important formations of Flooded Dense Shrubby/Herbaceous *Restinga* in places with several springs. This configuration is repeated throughout the system (SOARES, 2006) where the incipient fluvial input makes groundwater the main source of freshwater (CEPEMAR, 2000).

Soil characteristics and the presence of the *Restinga* vegetation favor the storage and maintenance of subsurface water as a result of percolation and of soil protection from direct sun incidence and consequent evaporation. The recharge and saturation of these aquifers enable water drainage towards the river's edges where springs occur (Figure 3). Thus, the region's rivers do not have classic springs normally related to mountains, being instead fed by springs both in their "heads" and all along their courses. In this process, a basic role is exerted by quaternary littoral strings, once the depressions formed among the mentioned crests canalize the water that arises in the lower areas occupied by mangrove forests at the rivers' edges (Figure 3) (SOARES 2006).

In the most upstream section of the Macaco River (Stations 11 and 12), with salinity varying from 24.3 to 25.7 ‰, only monospecific forests of *Laguncularia racemosa* occur. In the east river branch, the structural development is slightly superior to that of the west river branch, presenting a higher mean height, $\overline{DBH}$ and contribution in basal area of trunks with DBH above 10 cm. Besides the parameters analyzed, the high development of the trunk near the base of the tree demonstrates a community longevity that is not common for this species, normally associated with the initial stages of succession. Such fact indicates stability of the environmental conditions in this section of the river, which can also be related to the groundwater input that feeds the system.

The results of the characterization of mangrove forests clearly demonstrate the variation in the balance between marine influence and freshwater input that determines a salinity gradient, and consequently water and saline stresses gradient along the Macaco River. Thus, *A. schaueriana*, a more tolerant species to high salinities (MCKEE, 1995), has its occurrence restricted to the region with a higher marine domain at the river's mouth. In the intermediate stretch *R. mangle* dominates, but in the section with

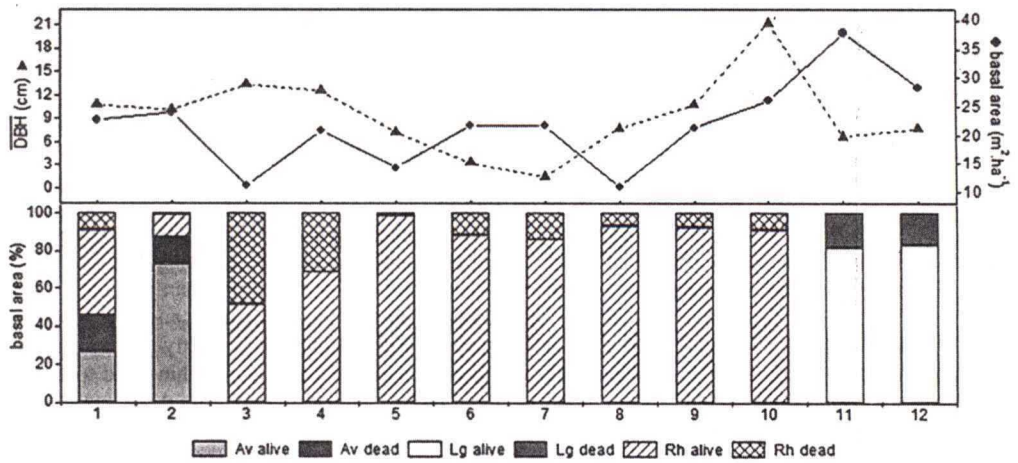

Figure 2. Structural characteristics of the mangrove forests from Macaco river. The stations were numbered upstream. Av = *Avicennia schaueriana*; Lg = *Laguncularia racemosa*; Rh = *Rhizophora mangle*.

the highest marine influence of this stretch, a higher contribution of dead individuals of this species is observed as a result of water and saline stresses. Upstream this species still dominates but in an environment of lower stress, on account of the higher influence of springs reflected in the higher structural development of the forests and lower contribution of dead trees. Finally, one can observe that *R. mangle* has been replaced by *L. racemosa*. There are several studies demonstrating the importance of the flow of freshwater from underground reservoirs for the maintenance of mangrove forests as observed in Caravelas (WOLANSKI and GARDINER, 1981; SEMENIUK, 1983; MAZDA *et al.*, 1990a, 1990b; WOLANSKI, 1992; WOLANSKI *et al.*, 1992; KITHEKA, 1998; DREXLER and DE CARLO, 2002).

Besides the influence of the water supply on the zonation of the mangrove forests, the described hydrologic system also influences the human population in the region directly, and not only through the maintenance of goods and services of the coastal ecosystems. The area between the Macaco and Massangano rivers has about 40% of its surface flooded by potable freshwater and presents countless sites with springs (SOARES, 2006). According to CEPEMAR (2000), the water supply in the municipality of the town of Caravelas is obtained through the capture collection of underground water in artesian wells that supply a system with an outflow capacity of 60 $m^3.h^{-1}$ and a storage capacity of 150 m^3. In the communities outside the municipality without a water supply network, the supply is also obtained from artesian wells, a fact that attests to the importance of underground water as a freshwater source for the entire region.

According to REBOUÇAS (2002), the Caravelas region is located in the coastal hydrogeologic province with one of the highest underground water potentials of the coastal sedimentary basins, with waters of excellent quality for human consumption.

For all these reasons, we note that the availability of groundwater is a key element for the perpetuation and connection

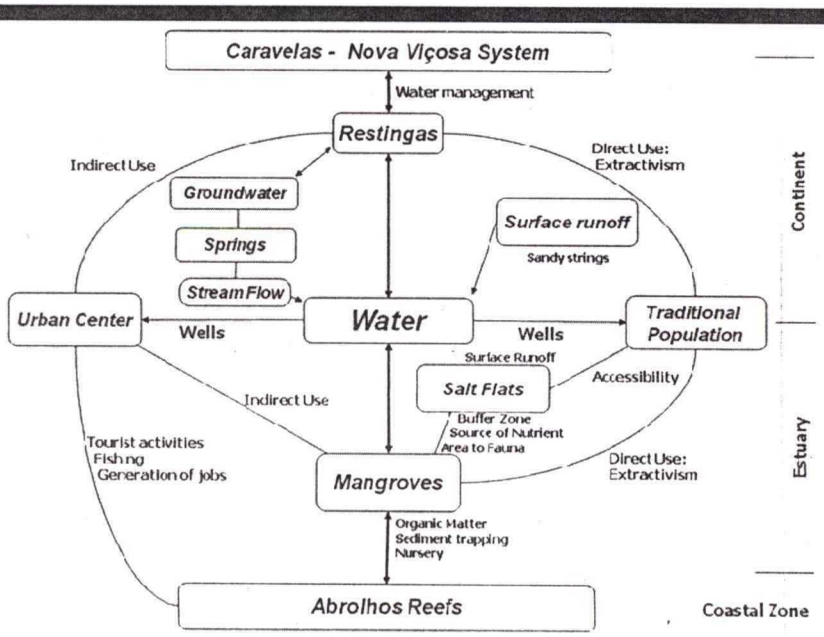

Figure 4. Conceptual model of connectivity among the local systems having as its agent the preservation and availability of freshwater in Caravelas - Nova Viçosa region.

of coastal ecosystems and human populations, both for the urban centers and the rural areas of the region.

SOARES (2006) define the behavior of this region as a large, delicate system between the towns of Caravelas and Nova Viçosa that is in a state of balance very similar to that presented by the the Macaco River. According to this author, the system involves interactions that surpass the estuarine system, exerting an influence on the inner areas of the continental shelf up to the Abrolhos reefs. This approach enables the understanding not only of the interactions within the estuary, but also in the coastal zone. Thus it was possible to propose a conceptual model of these relations in the region, which has water as an element of integration (Figure 4).

In this model the Caravelas - Nova Viçosa system appears connected to the Abrolhos Reefs by water, which in its pathway travels through several systems. Supposing that the water input occurs initially through precipitation, the diagram interpretation starts in the upper section highlighting the environmental service performed by the entire continental system, mainly related to the sandy strings and the *Restinga* vegetation, the former because of its characteristics of porosity and the latter because it promotes the preservation of this resource.

From this point towards the center of the diagram one can observe the path the water travels since its accumulation as groundwater, with its use by the *Restinga* vegetation (bidirectional arrow) until it emerges on river slopes. It is also noteworthy, in the opposite side, the direct surface runoff, which has more seasonal and intermittent characteristics.

The connection with the mangrove forests takes place in the estuarine region, represented here by the lower section from the central axis that divides the diagram. The balance between saltwater and freshwater is an important characteristic that will define the variability of forests in structural and functional terms, as was presented for the Macaco River. The main functions performed by the ecosystem are highlighted, particularly those related to the coastal zone where the Abrolhos reefs are found, in this case represented by sediment trapping in mangrove forests (TEAS, 1977; SNEDAKER, 1978; SAENGER *et al.*, 1983; CHOUDHURI, 1991; OTHMAN, 1994) and the flow of energy that is transferred through the feeding of juvenile reef fish and of fish of commercial value (SASEKUMAR *et al.*, 1984; CINTRON, 1987; HUTCHINGS and SAENGER, 1987).

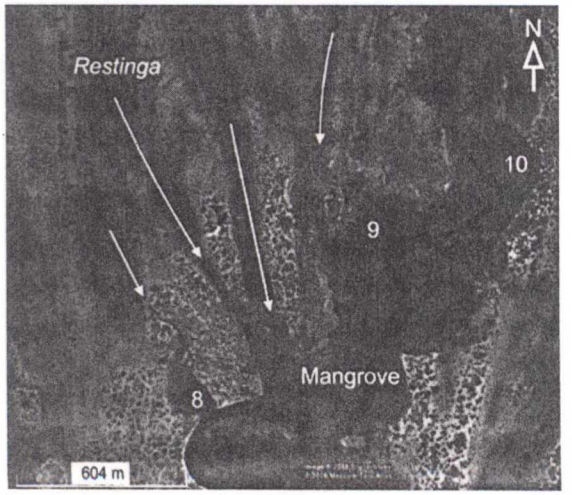

Figure 3. Surface runoff between sandy strings at the most upstream section of the Macaco River (white arrows indicate flux direction).

The salt flats located in zones above the mangrove forests are associated with mangrove areas, being flooded only by spring tides, which in association with high evaporation rates, results in the accumulation of salts in the interstitial water. The importance of these plains is related to, among others factors, its function as a buffer zone for the forest against geomorphologic and hydrologic changes, constituting a successional stage of the forest, besides serving as a source of nutrients for mangrove forests (SOARES 2006).

The human populations here are divided among urban centers and traditional populations and relate differently to the biological systems and the water. The urban population collects water for consumption from artesian wells and uses the water quality in the estuarine and coastal zones directly through the generation of jobs and income, as is the case of fishing and tourist activities around the Marine National Park of Abrolhos, which generate an economic chain including transportation, hotels, restaurants and other services. These urban centers enjoy also indirectly the quality promoted by the coastal ecosystems, which provide cost-free maintenance of many services.

With respect to the traditional populations, other forms of exploitation besides the direct collection of water for consumption from artesian wells were identified. These relationships with the biological systems are more direct, as a large parcel of the resources necessary for the survival of these families (food and housing) is extracted from the *Restinga*, mangrove or estuarine region (fishing), demonstrating a high dependence on the natural system. A significant number of these families live in deep poverty far from urban centers, which they visit regularly. For these trips they make use of areas such as *Restingas* and salt flats, this fact points out to the importance of these areas also as means of access to the manufactured resources not available in the biological systems, as well as for the transportation and outlet of products from the region's natural systems.

The diagram represents a synthesis of the delicate relations that take place in this region, which demonstrates how different and apparently disconnected systems are intimately related in this balance in the coastal zone.

CONCLUSION

Mangrove forests estuarine zonation reflects the variation in the balance between marine influence and freshwater input that determines a salinity gradient, and consequently water and saline stresses gradient along the Macaco River. The maintenance of mangroves and their associated resources depends on the integrity of the water supply that occurs all along the course of the rivers through springs at *Restinga* system.

The importance of the conservation of the natural resources of the Caravelas-Nova Viçosa region is also strategic for the survival of these regions' communities, as it guarantees the integrity of the systems from where these populations obtain their resources and is fundamental for the maintenance of freshwater availability for human consumption and activities related to agriculture and cattle raising. Other important relationships can be affected if this balance is modified, as it is the case of this region's connection with the Abrolhos Reef Bank, which can be affected if the mangrove loses its functions of sediment trapping (control of turbidity) and of being a nursery for some species of reef fish or as organic matter and nutrient source for the adjacent marine systems.

Therefore, the preservation of the coastal ecosystems of the Caravelas-Nova Viçosa region is strategic for both the maintenance of biological and functional diversity and the survival of these regions' communities, as any disturbance in the existing

relations among the local systems can modify the landscape profoundly.

LITERATURE CITED

ANDRADE, A. C. S. and DOMINGUEZ, J. M. L. 2002. Informações geológico-geomorfológicas como subsídios à análise ambiental: o exemplo da planície costeira de Caravelas – Bahia. Boletim Paranaense de Geociências, 51: 9-17.

CEPEMAR. 2000. *Estudo de impacto ambiental – Terminal de barcaças para embarque e desembarque de toras de eucalipto da Aracruz Celulose S.A., em Caravelas – Bahia.* Volume I/II. Dezembro, 2000.

CHOUDHURI, P.K.R. 1991. Biomass production of mangrove plantation in Sundarbans, West Bengal (India): a case study. *Indian Forester, 117* (1): 3-12.

CINTRON, G. 1987. Caracterizacion y manejo de Areas de Manglar. *In: Anais do I Simpósio de Ecossistemas da Costa Sul e Sudeste Brasileira: Síntese dos conhecimentos.* Vol. 3. Academia de Ciências do Estado de São Paulo. Cananéia, São Paulo. pp. 77-97.

CINTRÓN, G. and SCHAEFFER-NOVELLI, Y. 1984. Methods for studying mangrove structure. *In: The mangrove ecosystem: Research Methods.* Ed. S.C. Snedaker e J.G. Snedaker. UNESCO, Bungay, United Kingdom. 251p.

DREXLER, J.Z. and DE CARLO, E.W. 2002. Source water partitioning as a means of characterizing hydrologic function in mangroves. *Wetlands Ecology and Management*, 10: 103–113.

EWEL, K.C., TWILLEY, R.R.; ONG, J.E. 1998. Different kinds of mangrove forests provide different goods and services. *Global Ecology and Biogeography Letters, 7*: 83-94.

HUTCHINGS, P.A. and SAENGER, P. 1987. *Ecology of mangroves.* University of Queensland Press. Brisbane. 388p.

KITHEKA, J.U.1998. Groundwater Outflow and its Linkage to Coastal Circulation in a Mangrove-fringed Creek in Kenya. *Estuarine, Coastal and Shelf Science, 47*: 63–75.

LEIPE, T.; KNOPPERS, B.; MARONE, E.; and CAMARGO, R.. 1999. Suspended matter transport in coral reefs waters of the Abrolhos Bank, Brazil. *Geo-Marine Letters*, 19(3):186-195.

MAZDA, Y.; SATO, Y.; SAWAMOTO, S.; YOKOCHI, H. and WOLANSKI, E. 1990a. Links between physical, chemical, and biological processes in Bashita-minato, a mangrove swamp in Japan. *Estuarine,Coastal and Shelf Science, 31*: 817–833.

MAZDA, Y.; YOKOCHI, H. and SATO, Y. 1990b. Groundwater flow in the Bashita-Minato mangrove area, and its influence on water and bottom mud properties. *Estuarine, Coastal and Shelf Science, 31*: 621–638.

MAZDA, Y.; MAGI, M.; KOGO, M. AND HONG, P.N. 1997. Mangroves as a coastal protection from waves in the Tong King delta, Vietnam. *Mangroves and Salt Marshes*, 1: 127-135.

MCKEE, K. L. 1995. Seedling recruitment patterns in a Belizean mangrove forest: Effects of establishment ability and physico-chemical factors. *Oecologia* 10 (1):448-460.

OTHMAN, S.B. 1994. Value of mangroves in coastal protection. *Hydrobiologia*, 285: 277-282.

PEREIRA, O.J. 1998. A função da zona costeira na qualidade ambiental - Restingas e manutenção da qualidade ambiental da zona costeira. *In: Anais do Simpósio de Ecossistemas Brasileiros.* Vol. 5. Academia de Ciências do Estado de São Paulo. Águas de Lindóia, São Paulo. pp. 173-178.

REBOUÇAS, A.C. 2002. *Águas Subterrâneas. In:* A.C. Rebouças; B. braga; J.G. Tundisi (eds.). Águas Doces no Brasil: Capital Ecológico, Uso e Conservação. Escrituras, São paulo. pp. 119-151.

SAENGER, P.; HEAGERL, E.J. and DAVIE, J.D.S. 1983. Global status of mangrove ecosystems. *Environmentalist*, 3 (Supl.3): 1-88.

SANTOS, C.R. 2001. *A interface das políticas públicas com o processo de ocupação humana na área de preservação permanente: vegetação fixadora de dunas na Ilha de Santa Catarina, SC.* PhD. Thesis. Universidade Federal de Santa Catarina. 402p.

SASEKUMAR, A.; ONG, T.L. and THONG, K.L. 1984. Predation of mangrove fauna by marine fishes. *In: Asian Symposium on Mangrove Environment Research and Management.* Kuala Lumpur, Malaysia. pp. 378-384.

SILVA, S.M. 2002. *Diagnóstico das Restingas no Brasil.* Report to Ministério do Meio Ambiente, 30p.

SNEDAKER, S.C. 1978. Mangroves: Their value and perpetuation. *Nature and Resources, UNESCO,* 14 (3): 6-13.

SOARES, M.L.G. (COORD.). 2006. Laudo Biológico do Sistema Caravelas – Nova Viçosa com vistas à criação da Reserva Extrativista do Cassurubá. Relatório Técnico Final para o Processo de Criação da Unidade de Conservação. Cooperação: IBAMA e Conservação Internacional, 246p.

SUGUIO, K; MARTIN, L; BITTENCOURT, A.C.S.P; DOMINGUEZ, J.M.L and FLEXOR, J.M. 1985. Flutuações do nível relativo do mar durante o Quaternário superior ao longo do litoral brasileiro e suas implicações na sedimentação costeira. *Revista Brasileira de Geociências*(1985),15: 273-286.

TEAS, H.J. 1977. Ecology and restoration of mangrove shorelines in Florida. *Environmental Conservation*, 4 (1): 51-58.

UNEP-WCMC. 2006. *In the front line: shorelineprotection and other ecosystem services from mangrovesand coral reefs.* UNEP-WCMC, Cambridge, United Kingdom. 33 p.

WOLANSKI, E. 1992. Hydrodynamics of mangrove swamps and their coastal waters. *Hydrobiologia,* 247: 141–161.

WOLANSKI, E. and GARDINER, R. 1981. Flushing of salt from mangrove swamps. *Australian Journal of Marine and Freshwater Research,* 32: 681–683.

WOLANSKI, E.; MAZDA, Y. and RIDD, R. 1992. *Mangrove hydrodynamics. In:* A.I. Robertson and D.M. Alongi (eds), Coastal and Estuarine Studies 41, Tropical Mangrove Ecosystems. American Geophysical Union, Washington, DC, USA, pp. 43–62.