MORPHOLOGICAL CHANGES OF THE MOUTH OF THE SÃO MATEUS RIVER, NORTH COAST OF ESPÍRITO SANTO, AND THE BIOGEOGRAPHICAL CONSEQUENCES TO THE MANGROVES

ALTERAÇÕES MORFOLÓGICAS DA FOZ DO RIO SÃO MATEUS, COSTA NORTE DO ESPÍRITO SANTO, E AS CONSEQUÊNCIAS BIOGEOGRÁFICAS PARA OS MANGUEZAIS

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ABSTRACT

This article deals with the morphological and biogeographic changes in the mouth of the São Mateus River, in the state of Espírito Santo, southeast of the Brazilian coast between 1970 and 2017. During this period, the mangrove ecosystem was destroyed by river-marine processes causing several problems to Conceição da Barra city, from the point of view of navigation, fishermen, pickers and tourist activities. The evolution of this part of the coast of the state of Espírito Santo shows that the river-marine processes, combined with the precipitation that occurred along the São Mateus River basin, changed dramatically in 1991, due to the increase of precipitation along the basin and consequent increase in water at the mouth of the São Mateus River. Such processes modified the estuarine characteristics that suffered erosive and depositional processes in the mangroves and in the restinga vegetation. On the other hand, these processes also allowed the colonization of new areas by mangroves and also by halophilic vegetation. These processes are being monitored by a Research Project that monitors the biotic and abiotic mangrove data and their replacement by other vegetation types since 1995. This paper presents changes in coastal morphology from a systemic perspective, based on several authors, integrating the attributes of vegetation and precipitation in the São Mateus River basin.

Keywords: Estuary, Coastal processes, Mangroves.

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RESUMO

Este artigo trata das mudanças morfológicas e biogeográficas na foz do rio São Mateus, no estado do Espírito Santo, sudeste do litoral brasileiro entre os anos de 1970 e 2017. Durante esse período, o ecossistema manguezal foi destruído por processos flúviomarinhos causando vários problemas ao município de Conceição da Barra, do ponto de vista da navegação, dos pescadores, dos catadores e das atividades turísticas. A evolução desta parte do litoral do Estado do Espírito Santo, mostra que os processos flúviomarinhos, combinados com a precipitação que ocorreu ao longo da bacia do rio São Mateus mudaram dramaticamente em 1991, devido ao aumento da precipitação ao longo da bacia e ao consequente aumento da água na foz do rio São Mateus. Tais processos modificaram as características estuarinas que sofreram processos erosivos e deposicionais nos manguezais e na vegetação de restinga. Por outro lado, esses processos também propiciaram a colonização de novas áreas por manguezais e também por vegetação halofílica. Esses processos estão sendo monitorados por um Projeto de Pesquisa que monitora os dados bióticos e abióticos dos manguezais e a substituição por outros tipos de vegetação desde 1995. Este artigo apresenta mudanças na morfologia costeira sob uma perspectiva sistêmica, baseado em vários autores, integrando os atributos de vegetação e precipitação na bacia do Rio São Mateus.

Palavras chave: Estuário, Processos costeiros, Manguezal.

Introduction

Mangroves comprise an association of flora and fauna characteristic of the coastal zone, composing the transition environments between the hinterland and the oceans. According to Giri et at., (2010, p.1) *the global distribution of mangrove is believed to be delimited by major ocean current and 20^{0}C isotherm of sea water in winter*.

Spalding et al., (2010, p.2) estimated that the total mangrove forest area of the world in 2000 was 137,760km^2. The continued decline of the mangrove forests is caused by conversion to agriculture, aquaculture, tourism, urban development and overexploitation.

Among the necessary basic requisites for their development and maintenance, are highlight tropical temperatures, presence of freshwater favoring the creation of salt-water environment, tides' amplitude which propitiates the penetration of salt water for the interior of the continent, sheltered littoral reliefs, protected of the forces from the waves and tides. Considering the terms and requisites above cited, the mangroves of the Espírito Santo State are distributed along its coast since the north arm of the Doce Stream, on border of Bahia State, until the Itabapoana River, on the border with Rio de Janeiro State, whose area was 75km^2, according to Vale; Ferreira (1998).

In these environment acts many forces of different intensity and frequency. Such systems are highly subsidized by external sources of energy, from the solar radiation, and the tides, of the precipitation, of the input of freshwater and fluvial sediments, being captivated by the present vegetable species in the environment and transformed in forest structure (biomass) (SCHAEFFER-NOVELLI *et al*., 1990b). The structural development of the vegetable species will be a reflex of the availability combination of an abundance of these sources, presented altogether.

On the other hand, there are tensors, or impacts, which divert energy of the system, making it adapts itself, or not, front to the tension conditions, such as long period of drought, high index of salinity, excess of sediments input, among other things. To the interaction among forces and the answers of the environment, Odum (1969), denominates *energetic signature*. The probability of this signature prints similar characteristics to physiognomic and structural development of woodlands along its distribution band, led several authors to classify the environments where occur mangroves, above all geomorphologic manner, in different space scales (TWILLEY et al., 1993).

Thus, Bruce (1982) established a classification of such environment, whose recognition enables differentiate the factors that influence the distribution and the physiognomy of mangroves in a coastal region. For the author, the three main components that govern the geomorphic typology or environmental compositions of any place are the geophysical, geomorphic, and the biological (VALE, 2009).

Metodology

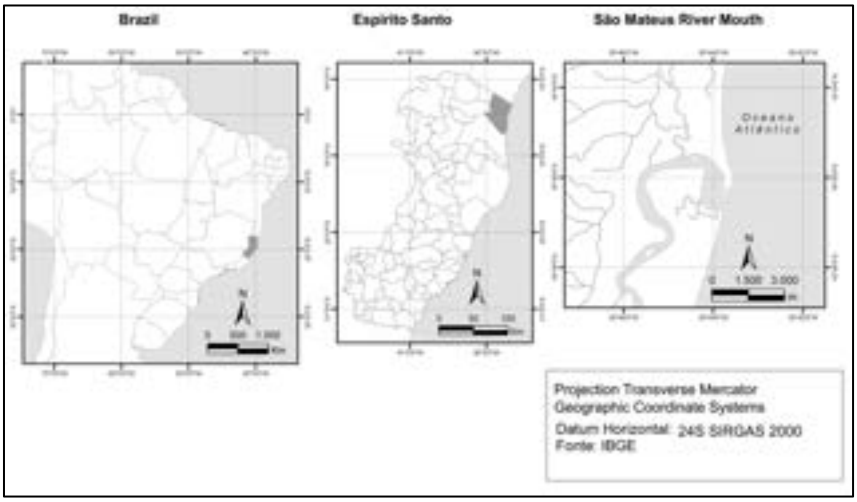
The theoretic-methodological assumption idealized by Ab´Sáber (1969) and Ross (1992), as well as of that proposed by Thom (1982) based this research. Therefore, to comprehend the geomorphologic and phytogeography modifications occurred on the mangroves of the estuary of the São Mateus River, among the years 1970 and 2017 the regional scale were tacked account. The hydrographic basin of the São Mateus River was the biggest analyzed space unit, whose climatic, hydrologic, geomorphologic characteristics and land use and land cover were interpreted.

Field campaigns were carried out in order to ratify the information obtained in the cabinet. Precipitation data of the basin meteorological station were systematized to ascertain the climate data. Finally, were realized several field trip to analyze the mangroves and others kind of vegetation of the estuary of the São Mateus River mouth - understood here not just as the properly mouth, but also as its adjacent areas - where the details of the temporal-space dynamic were more perceptible and especially important. In the areas covered by mangroves a phytosociological survey was carried out, which followed the methodology proposed by Schaeffer-Novelly; Cintrón-Molero (1986). Eight transects of the water line were draw towards the mainland, whose extension changed according to the architecture of the forest.

Study area

The study area is located in the estuary of the São Mateus River, more precisely in the mouth and theirs adjacent areas, in the county of Conceição da Barra, in Southeast Coast of Brazil (Fig. 1).

Figure 1 – Location of the studying area.



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Results and discussions

In 1970 the mouth of the São Mateus River present emerged sedimentary banks, probably resultant features of the ebb tide. Two sedimentation banks also were visible inside what we call *estuary lagoon* (Fig. 2). The mangroves located to the right margin of the mouth were very exuberant. To the left margin, almost parallel to the coastline, there was a fluvial bar with about a kilometer of extension and 375m of width. Apparently, in this time, did not yet occur the erosion and sedimentation complex processes accelerated about the mangroves to the right margin, neither the erosion on Bugia's Beach, to the left margin.

In 1991 two sedimentation banks that in 1970 were present in the *estuary lagoon*, just one was observed, whose configuration was strongly modified and in colonization processes by mangroves. The remaining of the fringe introduced a decrease of mangrove area. To the right margin, so close to the Pontal do Sul, for example, an area of 650.000m² of mangrove there was missing (Fig. 3). The fluvial spit, to the left margin of the river, that was occupied by the local population, it lengthened to the interior of the *estuary lagoon* for more 800m, present two kilometers of extension and 120m of width.

Figure 2 – São Mateus River Mouth and adjacent area in 1970.

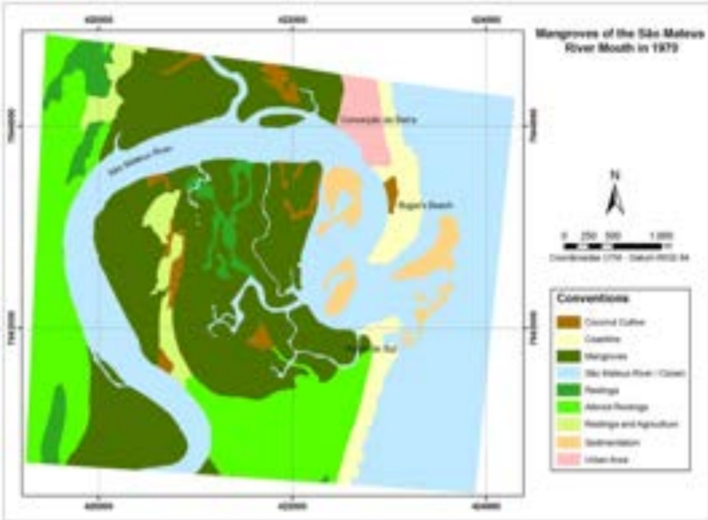

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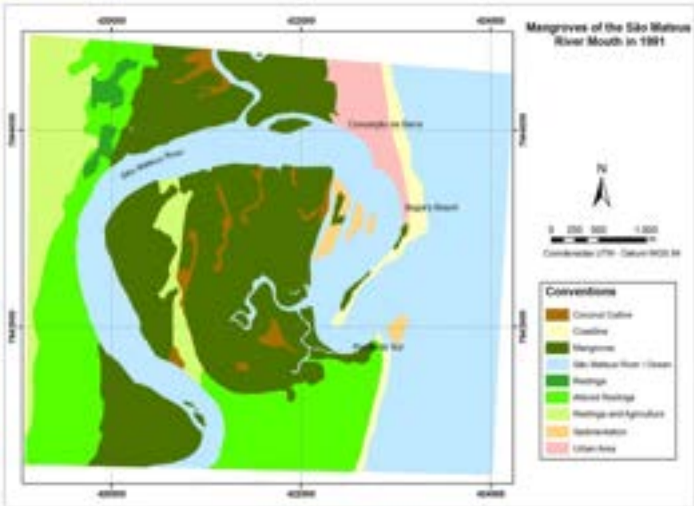
Figure 3 – São Mateus River Mouth and adjacent area in 1991.



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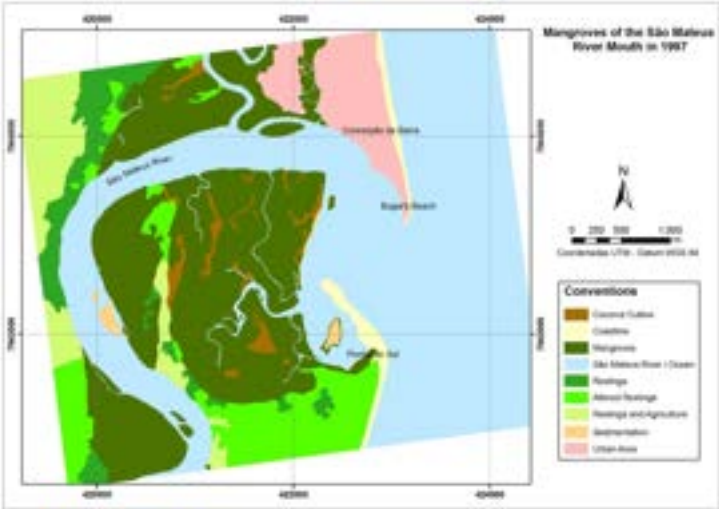
In 1997, the configuration of the mouth continued to be changed. The erosion processes, to the left margin, destroyed large part of had remained of the fluvial spit, which probably broke in 1992, and it reached streets and edifications on Bugia's Beach (Fig. 4). This can be explained by the increase in rainfall that occurred along the São Mateus River basin in 1991, whose rainfall was twice as high as the average (VALE; ROSS, 2010).

The sand bank, resultant of the breaking of the spit, remained inside the lagoon, shows morphologic alterations. However, the development of the vegetation about that bank was notorious. The right margin introduced now a fluvial spit very developed that, together with the bank above mentioned, almost isolated the *estuary lagoon*.

Figure 4 – São Mateus River Mouth and adjacent area in 1997.



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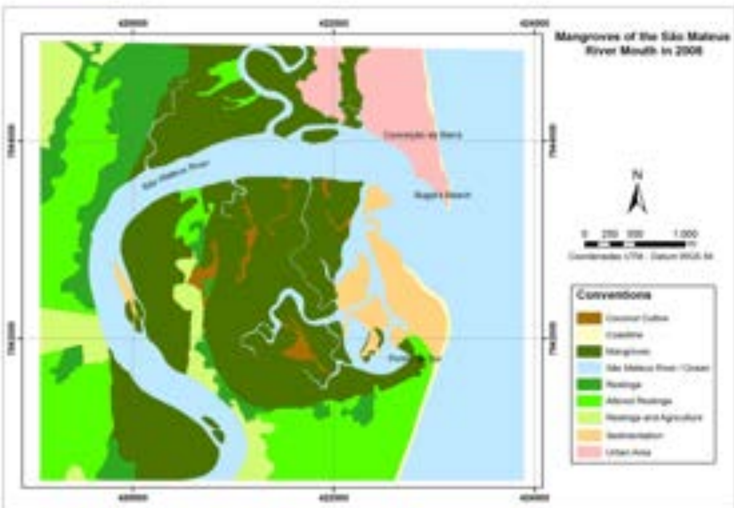
The configuration of the mouth of São Mateus River in 2008 (Fig. 5) suggests that the transport of sediment from the longitudinal current from south to north predominates, since the amount of sediment in the mouth is impressive.

It is observed that the mangroves already colonize the island that remained of the erosive processes that occurred before. However, neither mangroves nor other vegetation still colonizes recent sediment banks (Fig. 5).

Figure 5 – São Mateus River mouth and adjacent area in 2008.



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In 2017 the mouth of the São Mateus River presents a chaotic sedimentation (Fig. 6) that allowed the colonization by mangrove seedlings that currently compose a mixed forest with the species ***Rhizophora mangle*** (L.), ***Laguncularia racemosa*** C.F.Gaertn, ***Avicennia germinans*** (L.) and ***Avicennia schaueriana*** (L.). However, there is a predominance of ***L. racemosa***, probably due to the nature of the sandy sediments that constitute the soil (Fig. 7). The presence of psamophytic vegetation in the mouth is remarkable in 2017, where there is a great amount of substrate available. The position of transects are shown in figure 6, such transects continue to be monitored by recent research guided by us.

Figure 6 – São Mateus River mouth and adjacent area in 2017.

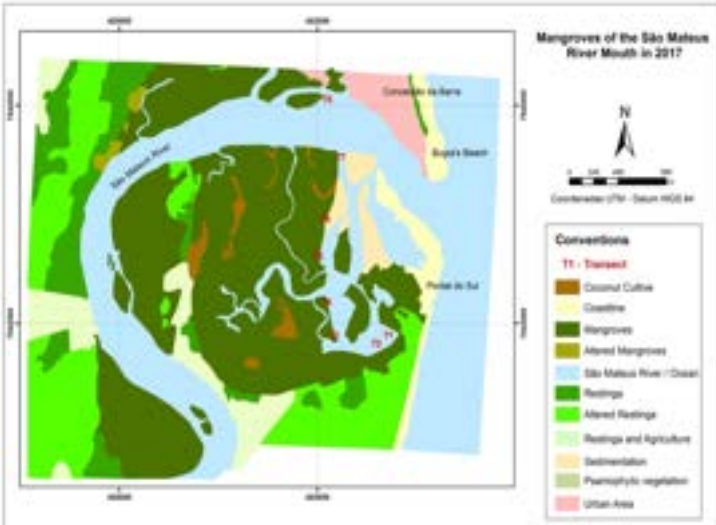

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Figure 7 – New accretion areas of the São Mateus River mouth in 2017 colonized by mangroves. Photography by authors.

Trough the interpretation of five morphologies of São Mateus River mouth and adjacent areas, as well as by the systematic observations of field along twenty two years, we can realize clearly that occurred and occur erosion and deposition processes that sometimes they destroy part of the mangroves, sometimes they enable its expansion. All geographical space, above all the coast, is exposed to the different magnitude and frequency modifications. However it is in front of very rapid alterations. Such geomorphic alterations are common along the Brazilian coast, mostly to the great estuary margins, such as Beberibe (PE), Jaguaribe (PE), São Francisco (PE/AL) (VALE; SCHAEFFER-NOVELLI, 2018), among many another, where the occupation accomplished without one preoccupation. In other words, these spaces have always been, throughout our history, the first place to be occupied, initially by the colonizers and later, gave rise to the great national cities.

In front of the verified facts emerge some questions: Which factors could explain such modifications? Would these processes be natural or would it result from anthropogenic actions? From these questions and based on the theoretic-methodological assumption above mentioned, it sought comprehend the action of the several elements that interact in a landscape. Thus, through the geomorphologic mapping was accomplished the characterization and compartmentalization of the morph-structural and morph-sculptural units that compose the basin of the São Mateus River, which enabled the apprehension of the relief in regional scope, as well as the comprehension of the own physiognomic aspects and different from each one of these units and its articulation, forming a single and indivisible landscape (PHILLIPS, 2007).

Reflecting about the probable "natural" causes, such as the alterations in the pluviometric and fluviometric index, in the São Mateus basin, elevated precipitation periods and flow generated erosive episodes and concomitant depositional in the mouth of this river, as much as they generated low precipitation and flow periods. The magnitude and the frequency of these depositional/erosive episodes is one answer to the variation of the magnitude and frequency of those precipitation/flow periods, sometimes elevated sometimes low (VALE; ROSS, 2010).

Being the man one of the elements that modify most the landscape, the verification of the land use and land cover of it showed the best analysis tool. However, the use data and occupation shown in this research just were qualitative, opening new fronts of research, inclusive experiments along the different terrains that compose the basin, to know the potentialities of uses and environmental fragility. The predominant activities along the part of the basin localized in Espírito Santo State, are the pasture and the farming. On the other hand, for monoculture of ***Eucalyptus sp.*** has grown a lot in the last 30 years, occupying great extensions of the tertiary terrains of the São Mateus basin.

The activities mentioned above affect, of different manners and intensity, the *hydrosedimentological cycle*, which involves the displacement, the transportation and the deposition of the present solid particles in the basin.

The damage and the risks of an eventual alteration in the *sediment cycles*, can extend to the ebb tide**,** for kilometers of distance from location of the alteration, and it can really reach the mouth, provoking erosive and sedimentary phenomena that, associates to the oceanographic elements, become difficult to be measured and controlled.

The comprehension of the paleogeographic evolution of the coastal plain of the North of Espírito Santo was extremely important to evaluate whether the analyzed morphologic alterations in the period from 1970 to 2017 could represent a tendency or can be cyclic alterations. However, the oceanographic parameters, such as the climate of waves - inductor of coastal processes, the littoral transportation and the tides, are variable of compulsory investigations inside this research line that, in this case, were not yet accomplished.

In spite of this fact, the analysis conception of the environments where occur mangroves, proposed by Thom (1982), for which should be investigated the biological, geomorphic and geophysical components, it was fundamental for the understanding of the genesis of the compartments of fluvial-marine accumulation occupied by mangroves in the estuary of the São Mateus River. In this work was evident the mangroves are great biological indicators of the geomorphologic and biogeographical alterations of the estuary regions.

In the transects 1 and 2 (Figs. 6 and 8), with the predominant process of slow deposition, occurs advance of mangroves; while in the transects 2, 3, 4, 5, 6, 7 and 8 whose processes belong to erosion and posterior accelerated deposition, occur fallback of mangroves (SEMENIUK, 1980; WOODROFFE, 1992) (Fig. 9). While destroyed mangrove areas are being quickly replaced by transition psamophile vegetation, where many of the species are dunes fixatives; the areas of slow sedimentation are being occupied for mangroves seedlings, which ones, through their qualities of r-strategists, occupy quickly the areas under propitious environmental conditions.

Figure 8 – Position of transects 1 and 2, with the predominant process of slow deposition, where occurs progradation of mangrove toward to *coastal lagoon*. Photography by authors.

Figure 9 – Position between transects 5 to 7 whose processes belong to erosion and posterior accelerated deposition, occur disruption of mangroves. Photography by authors.

In accomplished transects, mangroves answered to both erosion and sedimentation processes, of very visible form. In the fringe of transects 1 and 2 the re-colonization for ***Laguncularia racemosa*** (L.) C. F. Gaertn, ***Rhizophora mangle*** (L.) and ***Avicennia schaueriana*** (L.) and re-sprout of ***L. racemosa*** individualized a sector of the estuary in "progradation" of mangroves in direction to the water line (Fig. 8). In the others transects the effects on the vegetation were expresses through the loss of aerial biomass, such as branches and whole trunks (dead apical), until individuals' total death, which had their root systems exposed and tumbled, still alive, on the soil. These effects on the swamp were more visible and passive of being measured in the edge of the estuary, while near the interior of the forest, the effects were less perceptible.

5. Conclusions

Probably what was observed in 1995 during the first field work was the result of erosion by surface runoff water, which exposed the root system of mangroves, which, being without substrate and, consequently, without support, as they fell. As erosion is processed, the sediments were being washed away and increased the exhibition area susceptible to the action of waves and tides. This erosion is very similar to that described by Semeniuk (1980; 1994) to the northwest coast of Australia.

According to this author, sheet erosion occurs more easily during the neap tides, because during this period, the greater exposure of the tidal flat by evaporation to dryness, promotes the growth of salt crystals and disruption of aggregates of mud. After 2 or 4 weeks, the spring tide rapidly across the floor hard and muddy, the water fills the cavities (crab burrows), the crystals are dissolved salts, mud thins up and collapses. Within minutes the mud becomes a dense suspension, and the substrate, which is not easily washed, erode rapidly as a function of the flood tide. The top layer is removed as the ebb tide carries the muddy sediments of the sea.

The example of what occurs on the coast of Guyana (BLASCO et al., 1990), here also seems that erosion begins and intensifies after the death of the mangroves. According to these authors, the death of mangroves is not a consequence of coastal erosion, but a cause, perhaps the main one. In this regard, we reaffirm the important role played by mangroves geomorphological, whose death, natural or manmade, endangers the maintenance of the coastline. Bird; Ongkosongo (1980, p.4) claim that *The constructive and protective value of mangrove is often demonstrated where they have died back, or been cut down, exposing the substrate which is then rapidly eroded by waves scour.*

Improper use of land along the river generates impacts that reflect, ultimately, on the estuaries, but over the whole area covered by drainage, are checked several indirect impacts, among which may be cited organic pollution water and sediment, addition of toxic substances, heavy metals and oil in water and sediments, increased turbidity, siltation of the main river and tributaries, damming of rivers and modification of routes and sections of river channels. Some impacts that occur in the basins can somehow benefit from the mangroves. For example, increased sediment loads, caused by erosion, may favor the expansion of mangroves on deltaic areas and toward the water line, be it river or sea. In other words, it allows an increase in mangrove areas wherever such processes occur. However, there is a balance between the river and marine systems aimed at maintaining stability of the vegetation in the estuarine regions. To what extent is this a benefit? Many factors must be considered in this regard, for example, the sedimentation rate may be higher than the system is able to receive. What are the biochemical conditions of the sediment arriving at the basic level on which to develop a whole system? Thinking about the landscape as a whole, nothing can be neglected when trying to understand the dynamics along a river basin, because it is an integrated system, whose consequences will give at the grassroots level topography that in this case, is occupied by mangroves.

Therefore, in a hierarchical system analysis, i.e., with different spatial scales, they must all be considered; therefore, to understand the behavior of mangroves in a level of detail, we must seek explanations in larger spatial units at a level hierarchy above and so on. In this sense the watershed is a spatial unit from which studies can be started and moorings with smaller spatial levels. Nowadays it is very important to concern about the sea level changes and the role of mangrove play in maintenance of coastal environments (SCHAEFFER-NOVELLI et al., 2016). In Conceição da Barra, for example, the loss of mangrove areas requires a concern with the loss of ecosystem services as well.

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