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SPATIAL PATTERNS OF MANGROVE ECOSYSTEMS: THE BRAGANTINIAN MANGROVES OF NORTHERN BRAZIL (BRAGANÇA, PARÁ)

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Abstract. This paper provides a baseline geographic characterization of the mangrove ecosystem of the Bragantinian coastal region in the State of Pará, northern Brazil, which is the research area of the joint Brazilian-German Mangrove Dynamics and Management (MADAM) project. The paper looks at the natural environmental conditions, the status of the coastal resources, the socio-economic situation of the rural population and the sustainability of existing human activities based on stock-taking between the years 1997 and 2000. Human use of this mangrove ecosystem is characterized by about 15 products, which have either subsistence value or generate monetary income for the local rural population. The importance of these functions for the rural household increases with the distance from the urban center. In the primary production sector, agriculture and artisanal fisheries are the main sources of income in the wider Bragantinian region. Both industries are characterized by many small operators. The industrial sector is very underrepresented throughout the region. In the service sector, especially coastal tourism is gaining increasing importance. It was found that the ecology of the ecosystem of Caeté River estuary as a whole can still be considered as rather undisturbed by human activities, but there is evidence of considerable and increasing remote and local interference by humans. This includes increased sedimentation by land clearance in the catchment area of the estuary, intensification of fisheries due to population growth and lack of alternative livelihoods, changes in the hydrological regime of the mangrove ecosystem by improvements to the network of roads, and development of tourism along the beaches. Presently the control of the allocation of resources within this region rests predominantly in the hands of local individuals. An overall plan for a sustainable management of the coastal zone is still lacking. *Accepted 13 September 2001.*

Key words: Mangrove ecosystem, spatial patterns, geography, socio-economics, coastal processes, fisheries.

INTRODUCTION

The littoral region of coastal Pará in NE Brazil is part of the world's second-largest continuous mangrove region estimated to cover a total area of 1.38 million hectares along approx. 6800 km of South American coastline (Kjerfve *et al.* 1997). This region is characterized by a viable mangrove ecosystem supplying a variety of human communities, which will be described in greater detail below, focusing on the western mangrove peninsula of the Bragantinian coastal region (W 46°76', W 46°52' and S 0°80', S 1°07') adjacent to the estuary of the Caeté river in northern Brazil. In comparison with the Indo-Pacific mangrove systems, the biodiversity of the mangrove ecosystem of the Bragantinian coastal region is comparatively small and can be classified as being part of the Atlantic mangrove province (Pernetta 1993).

Small-scale fisheries and small landholdings form the two dominant economic systems supporting the inhabitants of the Bragantinian coastal region. More than 80 % of the households derive their livelihood from the products of the mangrove estuary (Glaser, unpubl.). The most important mangrove product is the leaf-litter-consuming large semiterrestrial ocypodid crab *Ucides cordatus*, which reaches a carapace width of approximately 9 cm. The crabs are captured by professional collectors and are sold either alive on local or regional markets or are processed as meat for regional and national consumers. Fish, shrimp and other invertebrates, as well as mangrove timber, are also used, the latter predominately for the construction of fish traps (Barletta *et al.* 1998), fuel for domestic cooking, and to fire brickwork kilns (Berger *et al.* 1999).

Although the ecology of the Caeté ecosystem as a whole is considered relatively undisturbed by human activities, there is evidence of considerable and in-

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creasing local interference by humans, especially by the expanding tourist industry, increasing fishery activities, and urbanization. In this paper we provide results of a baseline geographic study within the Brazilian-German Project Mangrove Dynamics and Management (MADAM). Stock-taking was performed between the years 1997 and 2000.

SPATIAL BOUNDARIES

The Bragantinian mangrove system is part of the 2340 km² large municipality of Bragança. It is located at the estuary on the Caeté river in the vicinity of the town of Bragança, roughly 300 km southeast of the Mouth of the Amazon (Fig. 1). This area is part of the State of Pará and is assigned to the landscape group of the "Amazon Oriental" of North Brazil (Grabert 1991).

Geologically this region belongs to the Amazon lowlands, which are located between the crystalline Precambrian shields of the Guyanan and Brazilian highlands (Grabert 1991). Tectonic shear movements of these large shields have caused a break up of the Brazilian coastline, characterized by small peninsulas. The major environmental factors shaping this region were (a) the "tide-dominated allochthonous" processes (after the classification of Thom 1984) and (b) sub-

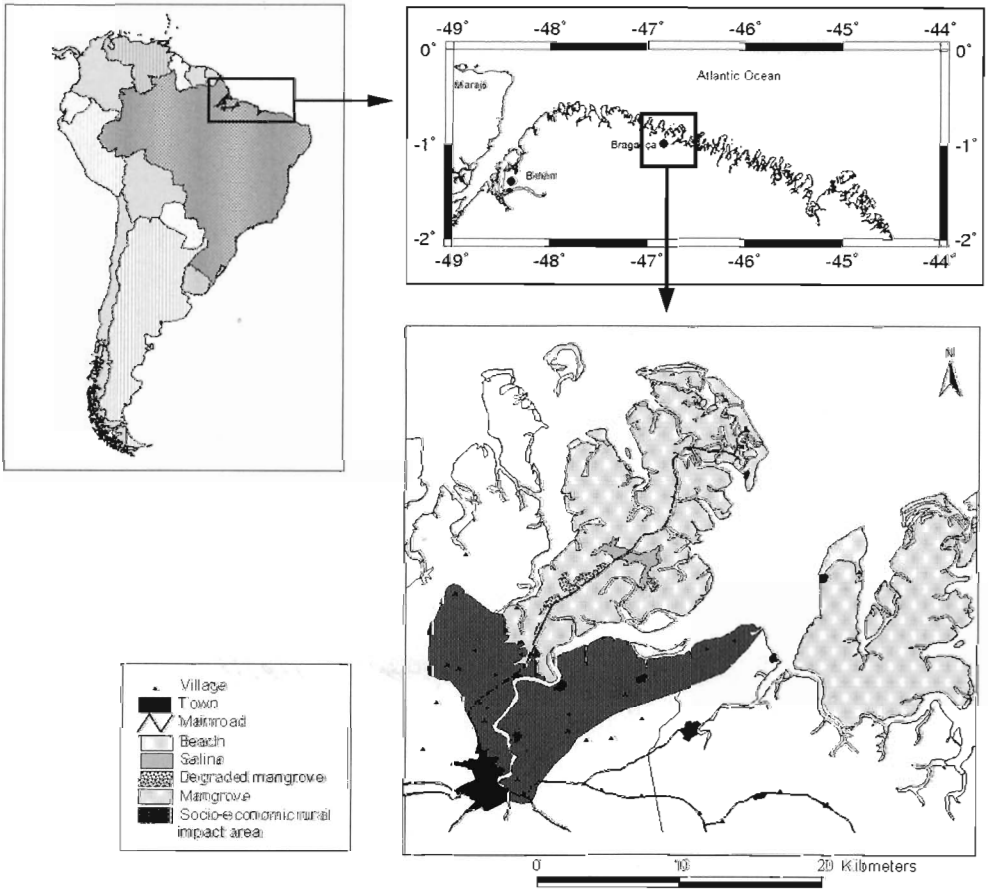


FIG. 1. The research area of the MADAM project in the State of Pará, northern Brazil. The dark shaded areas in the lower figure represent the area of the socio-economic rural communities which derive their direct income from mangrove resources within the Bragantinian coastal region.

stantial meteorological and hydrographic modifications occurring during the Pleistocene Ice Age.

In the following, "Bragantinian coastal region" is used to describe the 180 km² of mangrove ecosystem together with the adjacent 130 km² of rural area containing about 13 000 people who live and derive their livelihood from this mangrove peninsula. Communities that are not directly dependent on the mangrove resources are excluded in this definition.

The climatic region characterizing the Bragantinian coastal region is Inner Humid Tropics (Schultz 2000). The only seasonal change is the amount of rainfall. The drier season lasting from June through November is followed by a very wet period lasting from December to May. The annual rainfall exceeds 2545 mm (Souza Filho 1995). However, years with significantly less rainfall do occur and in recent years 2010 mm in 1997 and 1677 mm in 1998 were recorded. The measurements were taken at the weather station in Tracuateua, a town 15 km west of Bragança. At this station, the average annual temperatures recorded during 1973–1998 were 25.2–27.4 °C. Relative air humidity is always between 60 and 91%.

GEOGRAPHIC SETTING OF THE BRAGANTINIAN COASTAL REGION

Coastal geomorphology properties. The Bragantinian coastal region can be classified as a transgression coast, which with an average tidal regime of 4.5 m is classified as having a macro-tidal water regime. It consists of 3 morphologic units, which can be clearly differentiated according to their shape, lithology, stratigraphy, and vegetation. Starting inland and moving towards the coast, a coastal high plateau whose height ranges between 50 and 60 m forms the hinterland. It is predominantly composed of late Miocene and early Pleistocene sediments (Souza Filho & El-Robrini 1997). The second unit is located towards the north where the plateau dips progressively down to the coastal lowlands. The transition from the high plain to the coastal lowland is documented through a small fossil bluff of approx. 1 m elevation. The third unit is characterized by mangroves replacing the agricultural landscape and secondary vegetation of the plateau (Fig. 2). The watershed of the river Caeté and its tributaries within the municipality of Bragança

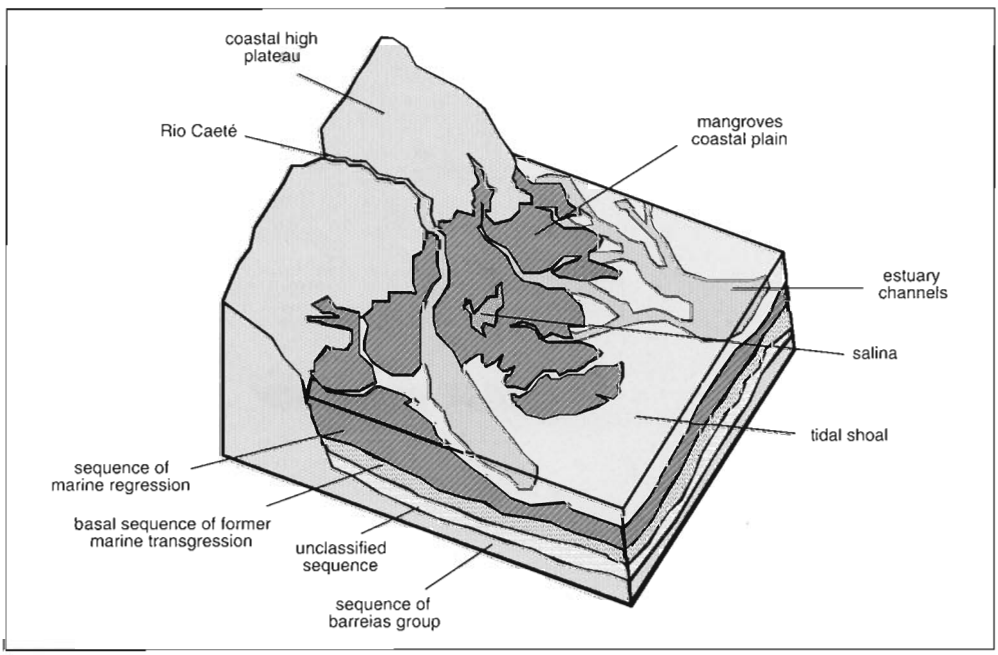


FIG. 2. Block diagram from a NE perspective with the major geomorphologic features and principle deposition sequences (Modified after Souza Filho 1995).

covers an area of about 450 km². Three smaller rivers drain an additional total of 445 km² of watershed area as fresh water input into the estuary of the Caeté river.

The mouth of the Caeté river on the north coast of the peninsula marks the northern boundary of the estuary while the emergence of the mangrove vegetation marks the southern border. This large area measuring 104 km² is the dominating geomorphologic feature of the coastal lowland within the Bragantinian coastal region. To the north the influence of the Atlantic Ocean gradually increases in this zone. The estuary consists of numerous channels which branch off into the mangrove peninsula of the coastal lowlands. Here, constantly moving sandbanks can be observed. Cheniers can be found in the transition zone between the mangrove and the dune ridges/beach complex.

The geology of the research area is formed by Precambrian cratonic block consisting of granites and migmatites. Palaeozoic sediments of the Bequimão formation overlay these, which are succeeded by the layers of the Piriá Camiranga. The following Mesozoic sediments are assigned to the formation Codó-Grajaú and Itapecuru. The Tertiary period is represented by the Pirabas layer formation with the subgroup Barreiras. The Quaternary is composed of Post-Barreiras sediments and recent depositions (Souza Filho & El-Robrini 1997, Behling *et al.* 2000).

The shore area in the northern part of the peninsula is divided into four beaches, one of which contributes significantly to tourist income to the local economy (Fig. 3).

A beach profile-monitoring program, carried out since 1997, shows that the majority of the coastline on the mangrove peninsula is subject to strong natural littoral transport. The fringing dunes along the north coast are very dynamic with maximum landward movement approaching 15 cm/day, covering

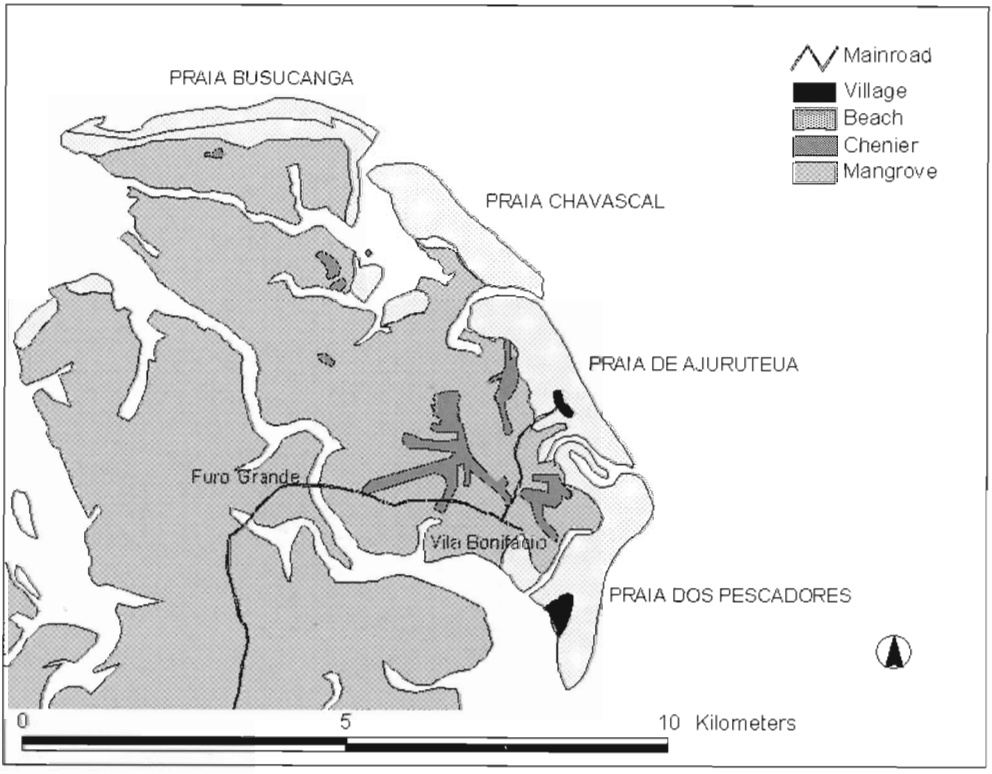


FIG. 3. The north coast of the Bragantinian coastal region (Map: G. Krause, ZMT (MADAM)) based on CPRM-Servico Ecologico do Brasil; Superintendência Regional de Belém).

mangrove vegetation on their way. This observation is verified by the exposure of fossil mangroves on the beach itself. Due to the strong coastal dynamics, the living costs are high along the shoreline as the repeated removal and reconstruction of local dwellings is required. Some residents have had to relocate as many as five times due to the rapid changes of the beach morphology. These developments have also impacted on the physical infrastructure such as roads, schools, and local sanitation, with health implications for the local population. Losses of weekend accommodation and tourist homes have also occurred leading to a decline in the associated tourism incomes.

Spatial vegetation patterns and utilization. Large areas of the tropical rain forest of the eastern Amazon, including the Bragantinian coastal plateau, have been burned and cut down to make way for anthropogenic activities. Remnants of the original tropical rain forest can be seen in a few areas. Local agriculture is based on the slash-and-burn method and shifting cultivation techniques, which characterize most of the agriculture in the Bragantinian region. The secondary vegetation is called locally "capoeira" and plays an integral part in the traditional crop-fallow cycle by maintaining the productivity of the areas subject to this form of agriculture (Henkel 1987, Kohlhepp 1987). Typical slash-and-burn activities near the town of Bragança result in the clearing of a patch of secondary vegetation at the end of the dry season. This is followed by the burning of the dried cut vegetation shortly before the onset of the rainy season. The ashes contain water-soluble mineral materials, which percolate into the soil providing natural fertilizers to the cultivated crops.

Along the coastal lowland, mangrove vegetation is the most remarkable feature of the region. Eighty-seven percent of the peninsula of the Bragantinian coastal region is dominated by three mangrove species (Fig. 4): *Rhizophora mangle* (Red mangrove), *Avicennia germinans* (Black mangrove), and *Laguncularia racemosa* (White mangrove).

The height of the mangrove stands varies from place to place caused by of different topographic environments, hydrological regime, and soil salinity. However, mangrove trees react to a wide range of environmental conditions by adapting structural properties like stem diameter, height, or leaf size. Tall mangroves measuring more than 25 m (Menezes pers. comm.) occur as well as dwarf forms of the same species no taller than 1 m. The latter are found in the less frequently inundated, central parts of the peninsula, which apparently offer less favorable growth conditions. Reduced water flow caused by the construction

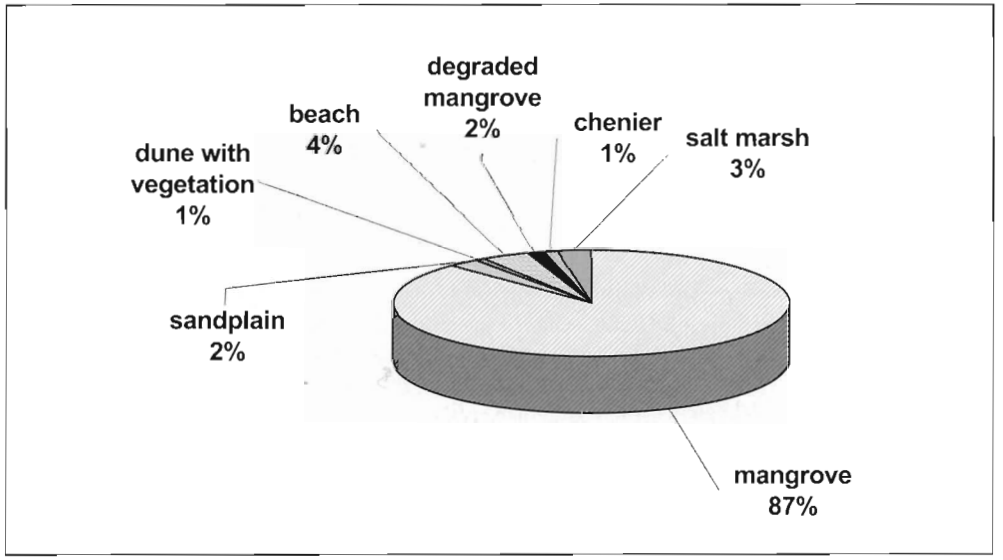


FIG. 4. GIS-calculation of the composition of the mangrove ecosystem on the 180 km^2-large peninsula.

of the PA 458 road between the city of Bragança and the village of Ajurureua has caused massive die-off through the modification of the local hydrological regime. This road was constructed during the 1970s. The massive cutting of firewood for local consumption is a problem, and local businesses (bakeries and brickyards) have accelerated this process. More recently, over 200 ha of mangrove were adversely affected by the changes in the natural environment. This has resulted in vegetation-free areas common to arid coastal landscapes. Presently an area more than four times the size of the existing mangrove area is subject to degradation. Although many saltmarsh plants can grow and reproduce in soil salinities three or four times higher than seawater, only very few of these have become established in the degraded areas.

The recently observed die-off in the area of the least-flushed mangroves close to the PA 458 may be a consequence of the dryness during the last few years. Strong defoliation of *Avicennia germinans* in 1998 was caused by moth larvae of the *Hyblae puera* complex throughout the peninsula as well as along the whole mangrove-dominated coastline of the State of Pará. This added to the stress on the mangroves. Direct degradation occurred because *Avicennia* trees suffering repeated defoliation did not recover. Local inhabitants cut a large number of defoliated trees, believing that the defoliated trees had died off, which added to the calamity. However, many of those trees were in the stage of recovery after the attacks by the larvae. The traditional selective cutting of *Laguncularia* and *Rhizophora* is for the construction of fishing traps. This activity is regarded as having a minor impact. A more significant problem is the growing population pressure on the entire mangrove habitat of the Bragantinian coastal region. Fisheries, as well as agricultural villages, with their infrastructure requirements are undergoing rapid development.

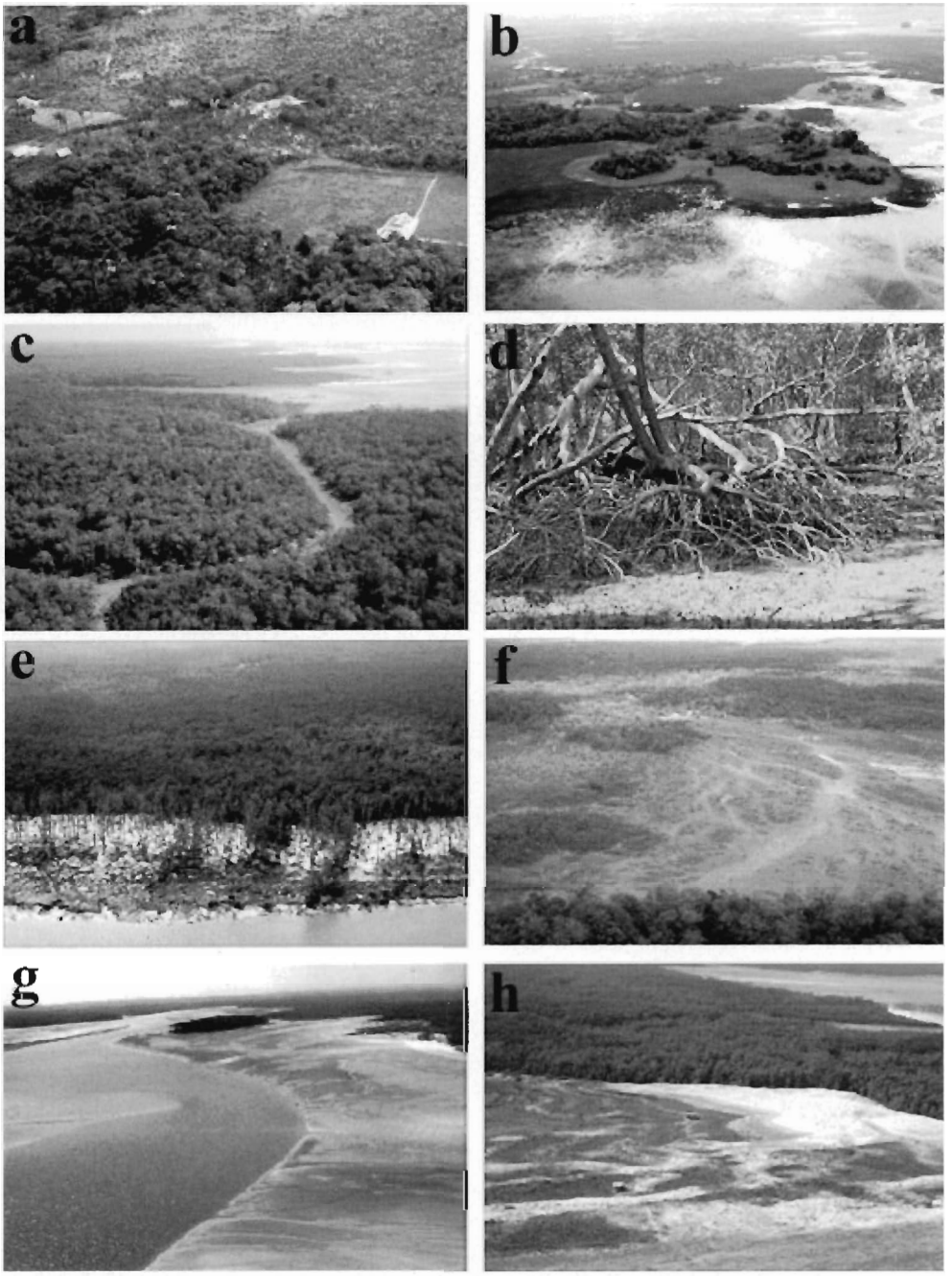
The macroalgae flora attached to the pneumatophores and lower branches of the mangrove trees is poor. The epiphytic flora is dominated by red algae, particularly of the genera *Bostrychia*, *Catanella*, and *Caloglossa*. Average dry weight does not exceed 1 g DW m^{-2} (Schories, unpubl. data).

Next to the mangroves, upper salt marshes at the Salinas dos Rochas are dominated by Cyperaceae (e.g., *Eleocharis* spp) and *Sporobolus virginiacus* (Poaceae) and located in the center of the peninsula (Menezes pers. comm.). They rarely become submerged, and apart from soil salinity they are influenced predominately by terrestrial factors. However, patches of small bushes of *Avicennia germinans* and *Laguncularia racemosa* occur within the salt marsh. Presumably variations in the local conditions, particularly the high salt concentrations, may prevent a more successful and widespread establishment of mangroves. During the rainy season the salt marshes become completely inundated. During periods of little precipitation the Salinas dos Rochas soils dry out. Because of the high evapo-transpiration, the mineral salts create a hardpan in the upper part of the soil profile. The cracks in the soil surface indicate the presence of a high proportion of small grain-size fractions. This phenomenon also occurs on the degraded soils.

Patches of restinga and coastal grassland (*campo de dunas*) occur on the sand plains and on the dunes along the north coast of the peninsula (Behling *et al.* 2000). Studies of the floral composition of these locations are presently underway; however, Cyperaceae, Poaceae, *Humiria balsamifera*, *Byrsonima crassfolia*, *Chrysobalanus*, and others are common here (Menezes, pers.comm.).

The ocean currents influence the productivity and the spatial distribution of phytoplankton. In the Bragantinian coastal region freshwater run-off and tidal mixing, as well the Amazon counter-current, influ-

FIG. 5. Physiogeographic properties of the mangrove peninsula. (a and b): Farms with small landholdings on the coastal lowland plain. The majority of the local farmhouses are built on the higher elevations. (c): The coastline of the mangrove peninsula at the estuary of the Caeté river. (d): *Rhizophora mange* trees within the mangrove peninsula. (e): Mangrove losses due to high sedimentation rates at exposed sites occur at various locations along the peninsula. (f): The degraded areas within the mangrove peninsula are inundated only during spring tide events. The flow channels of the water are visible on the sediment surface. (g): Mircophytobenthos organisms migrate to the sediment surface of the mudflats during day-time events of low tide. (h): Along the exposed north coast of the mangrove peninsula the beaches with vegetated and bare sand dunes are followed by salt marshes and mangrove. This is a highly dynamic environment (Photographs: D. Schories).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ence the outflow and direction of the estuarine plume on the continental shelf. In general, tidally induced mixing in relatively shallow coastal water prevents stratification within the estuary. However, phytoplankton productivity in the estuary might be enhanced by the increased nutrient fluxes from freshwater run-off. Salinity concentration in estuarine waters varies from 5 to 40‰. A total of 46 species of phytoplankton from at least 29 different genera were identified. The majority of these species belong to the Diatomeaceae class. During the annual cycle, total chlorophyl-A distribution varies between 0.08 and 25.10 mg m^{-3}. Chlorophyl-A values are significantly higher at low tide during the day compared to either low or high tides at night. Primary production in the small tidal channel is about 150 g C m^{-2} which is less than in the main channel and offshore (Schories & Soares 2001).

In summary, the Bragantinian mangrove system consists of a productive but endangered forest that is regularly inundated during spring tides. The coastal waters are rich in phytoplankton and resuspended microphytobenthic organisms. However, due to high loads of organic material within the Caeté river primary productivity in the water column is restricted.

Socio-economic characteristics. At the time of the European conquest of the South American continent during the early part of the 16th century, the Bragantinian region was occupied by tribes of the Tupinambás. The Tupinambás were the largest tribe and belonged to the language family of the Tupí (Henshall & Momsen 1974, Dickenson 1982). Towards the end of the late 16th century, the town Souza de Caeté was founded on the eastern shores of the Caeté river. Its name was later changed to Vila que Era. In 1753 the settlement moved to the west of the river Caeté, and the name again changed to Bragança (Ver-o-Pará 1998).

As elsewhere in the tropics, the population pyramid of the region is characterized by a high proportion of adolescents. The 1991 census revealed that of the 84 750 people living within the municipality of Bragança, more than 63% are less than 20 years old. The paved road to Belém, the BR-316, is the most important access road to and from Bragança, which has enhanced the fisheries sector by allowing marketing to a much larger area.

Bragança plays a key role in the supply of fish and other foodstuffs for the entire coastal region and the adjacent hinterland. The layout of the city center exhibits a gridiron pattern with several suburbs along the radial routes. Tight functional interlinkages exist between the town and its hinterland. For the rural population, the city of Bragança plays a major role as export channel for their products, as local market and administrative center. Coastal tourism on the north coast of the mangrove peninsula of Ajuruteua is developing as an important alternative source of income. The blacktop road (PA-253) from Bragança to Ajuruteua, which provides access to local beaches, facilitates tourist development. The relative proximity of the state capital of Pará (Belém) means high seasonal tourism peaks for the region. However, drinking water quality and waste and wastewater treatment have been extremely poorly managed, which has lead to a decline in the quality of the coastal beaches. The highly dynamic nature of the coastal environment has had a negative impact on the region's future economic development prospects. Particularly strong erosion has in turn led to a destruction of parts of the local tourist infrastructure (Krause *et al.* 2000).

Most rural households in the Bragança region have the multi-occupational structures typical of rural poor regions worldwide and engage in simultaneous multiple occupations and also utilize sequential seasonal opportunities for income generation. More than 80% of rural households depend on the diverse products of the Caeté mangrove estuary, and about 68% of the rural households derive monetary income from the mangrove ecosystem (Glaser *et al.* 1997, Berger *et al.* 1999). A main rural income source is the collection of mangrove crab (*Ucides cordatus*) which provides income and sustenance to about 42% of rural households. This is closely followed by fishing, which generates monetary income for about 30% of households (Glaser *et al.* 1997).

Over 41.6% of rural households of the region derive their income from farming. For them, agriculture forms an important complementary source of income. Subsistence slash-and-burn cultivation of mandioca, beans, tobacco, malva (a natural fiber), and rice are predominately found. Potential agricultural land adjacent to the mangrove is limited by high soil salinities. Households located close to the mangrove area engage more in the cultivation of cupuaçu and bacuri and other tropical fruit, which are all in high demand on the Brazilian market. Pockets of rice cultivation within the mangrove forest exist.

The rural population using the mangrove resources of the Caeté estuary resides in two spatially

distinct areas. Firstly, an area of about 50 km², situated on the west bank of the Caeté river, north of the town of Bragança, is mainly engaged in the primary sector (Fig. 1). Here access to the mangroves, which provide the major part of economic subsistence, is by bicycle, bus, or on foot. The exploitation of the mangrove crab (*Ucides cordatus*) occurs predominately according to the traditional system in which crabs are caught for live sale (Glaser 1998). With the paving of the road to Ajuruteua, crab and wood exploitation has intensified.

The second group of users of the Caeté estuary mangroves lives in an area of roughly 80 km² along the east shore of the estuary. This population is less well-connected to the urban primary production and employment markets since the local roads are not

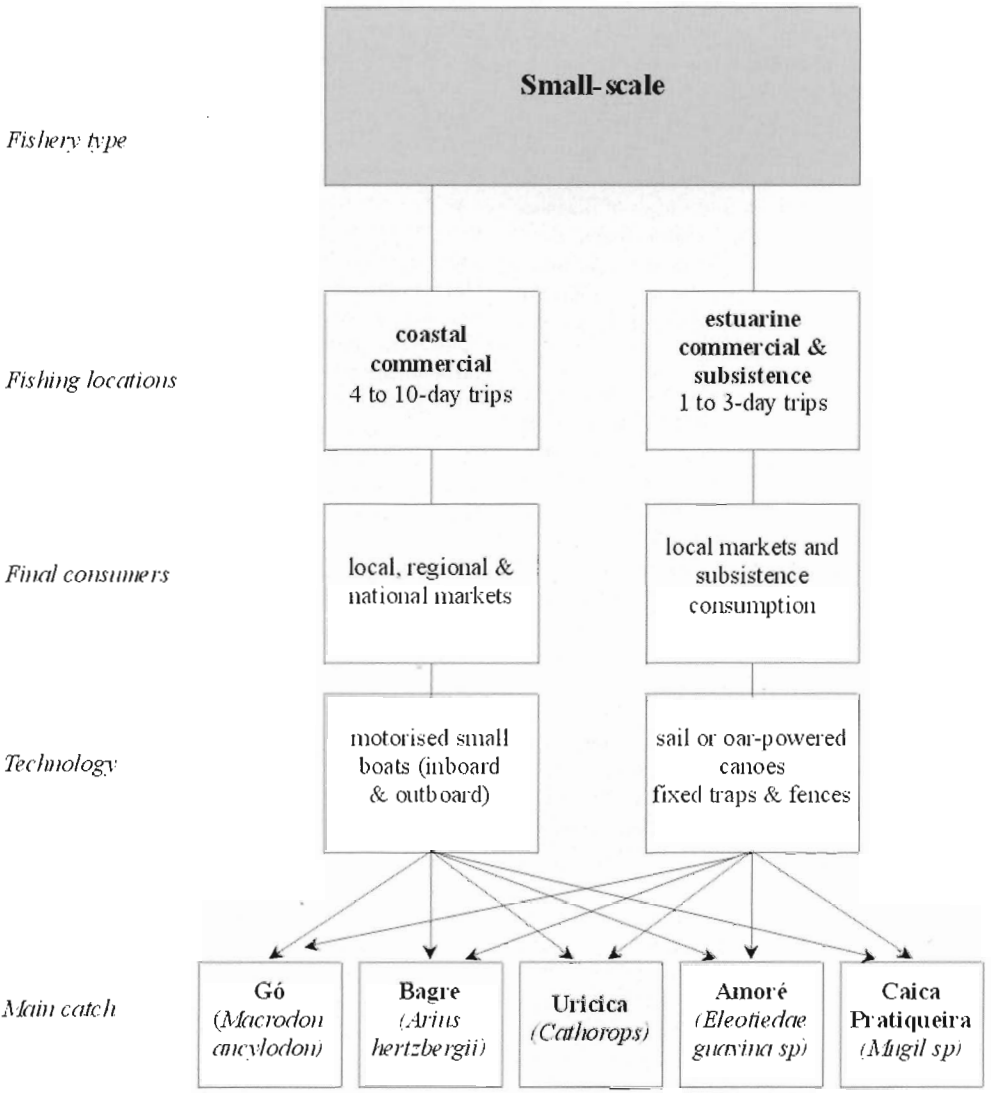

FIG. 6. The structure of fisheries in Bragança, Pará, Brazil. (Modified after Glaser & Grasso 1999).

paved. As a result, the local crab production and crab processing sectors are dependent on intermediaries and realize lower economic returns. Here there is only a small, patchy mangrove area fringing the coastline, thus access to the western large mangrove peninsula for this population is predominately by boat and the people use "modern" more predatory techniques (Glaser 1998, Diele 2000). Recent local overfishing problems have extended the spatial radius of the local crab fishery and caused conflicts with the crab fisher population of the western part of the estuary.

This spatial pattern is based on the findings of a rural census carried out in 1996/97 (Glaser *et al.* 1997). It was found that income diversity in the rural socio-economic area of the mangrove ecosystem was relatively high. Only about 31% of households had only one source of income, while a large proportion of these households consisted of single, often old persons. Villages located closer to the town of Bragança had a higher occupational and income source diversity than those further away from the local urban center. The fisheries sector is a significant source of income and subsistence for residents of the town of Bragança and surrounding villages.

Fishery patterns. Mangroves are part of the fisheries system of tropical coastal areas. In addition, the mangroves provide a range of commercial and subsistence non-fish products. In the Bragantinian coastal region, different types of fisheries can be distinguished by size, type of equipment used, and fishing areas. Before the introduction of nylon netting material, the main fishing devices of the region were traps (*curral*), cast nets (*tarrafa*), long lines (*espinhel*), and harpoons (*arpão*). Despite the introduction of new techniques, traditional devices such as large traps made out of wooden fences (curral) are still in use. These are constructed during the wet season on sandbanks along the Caeté estuary. Net barriers (tapagem) extended across small mangrove tidal creeks, in which fish are caught during ebb tide, are another common fishing method in the region (Barletta *et al.* 1998).

The local fisheries sector is entirely artisanal with a large-scale and a small-scale sector. Over half of the rural population in Caeté Bay engage in small-scale fisheries in the mangroves. Subsistence fishers who only occasionally sell part of their catch (Glaser & Grasso 1999) account for about half of these mangrove fishers, and commercial fishers for the other half (Fig. 6). One much-cited official statistic shows that 11.5 % of the total number of 4365 vessels in the State of Pará were registered in the Bragança region (IDESP 1989). Of the 502 fishing vessels registered there, 40 % were equipped with mostly low-power engines, 32% were non-motorized canoes, and 26% sailing canoes (Barletta *et al.* 1998). Thus the regional fleet is almost entirely artisanal, owner-operated and non-motorized.

According to IDESP (1989) and to the latest, ongoing data collection (V. Isaac, pers. comm.), Bragança's fishery contributes significantly to the regional economy. The artisanal fishery contributes half of the entire fish catch of the State of Pará; it also plays an important role in the supply of the local markets of the state capital of Belém, as well as of the neighboring state capitals São Luís and Fortaleza. The landings from the large-scale artisanal fishery are destined exclusively for the export market. Only a small part of the lower quality fish captured by Braganca's large-scale fisheries sector is sold in the local markets. Although most of the fish landings in the town of Bragança originate from the large-scale sector, there are clear indications that in terms of rural income generation and protein provision for local rural and urban households, small-scale mangrove fisheries play the predominant role in the Bragança coastal region (Glaser & Grasso 1999).

The most economically important mangrove product is the leaf-litter-consuming ocypodid crab *Ucides cordatus*, which is subject to high extraction rates by local crab-fishing communities. Over 60% of rural subsistence fisher households and over half of rural commercial fisher households also collect crabs for sale (Furtado 1990, Glaser *et al.* 1997).

Two types of crab fisheries can be distinguished. Traditional crab collectors sell their catch as livestock for local and regional consumption. The fishers live in Bragança or nearby villages such as Acarajó and Bacuriteua that are located west of the river Caeté. They enter the mangrove forest via the paved road that crosses the Caeté peninsula and catch the crabs in numerous intersecting tidal creeks, which are reached by foot or by small canoes. Traditional crab collectors only catch males with a carapace width between 6.5 and 9.1 cm, as livestock consumers reject small specimens and females (Diele 2000).

Modern crab collectors come from villages such as Term and Caratateua located east of the river Caeté. Their production is bought by the crab processing industry which is less concerned about size and sex of the crabs. However, modern collectors also aim for the largest males, but they retain smaller specimens

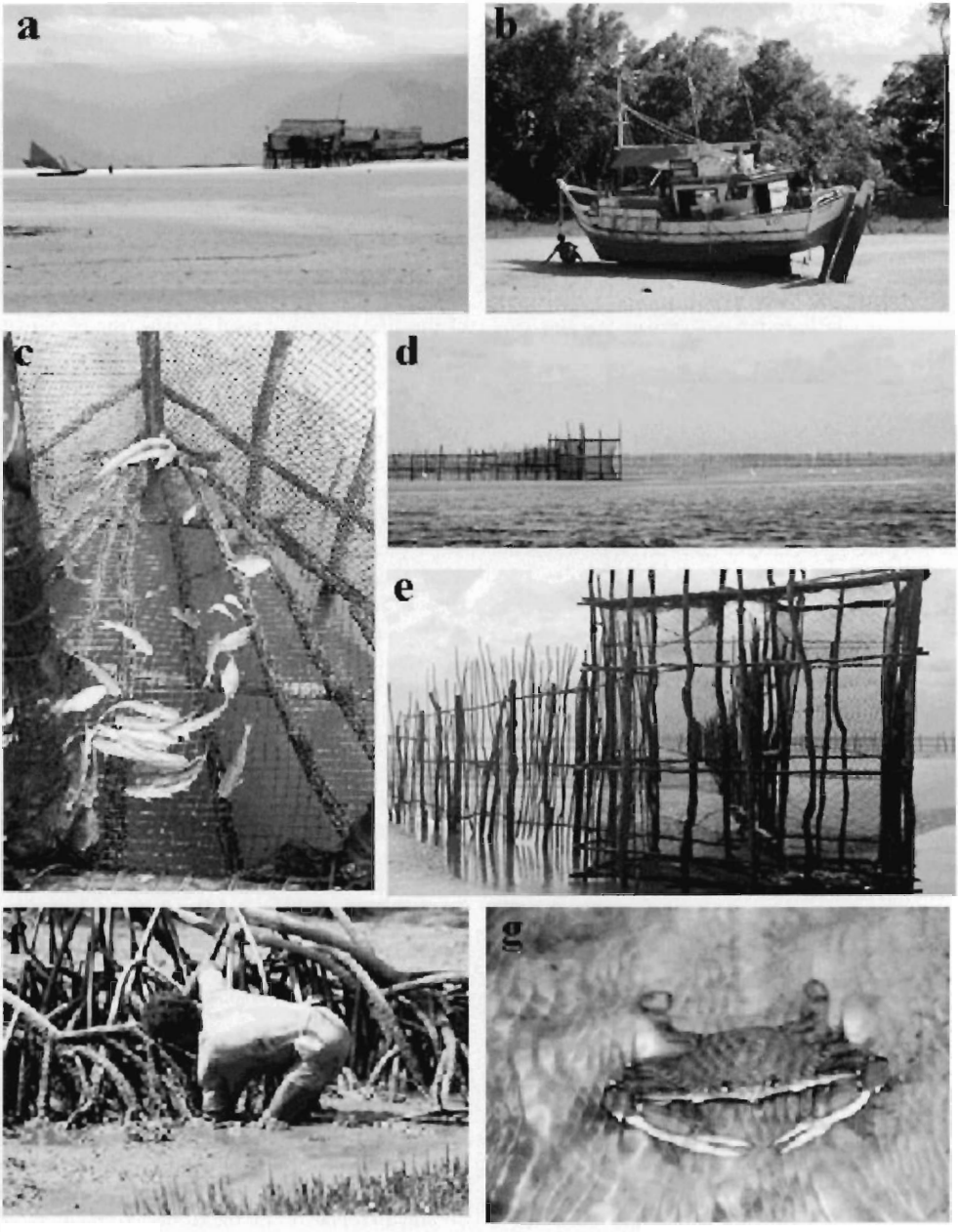

FIG. 7. Examples of utilization patterns of the mangrove resources. (a): Fishermen's camps (*ranchos*) are located at several spots along the coast. They serve as overnight shelter, for cooking purposes, and to treat and salt captured fish. (b): A typical fishing boat equipped with a low power engine at low tide. (c, d and e): *Currals* located along the sandbars of the Caeté estuary. These are traditional trapping barriers made of mangrove wood. (f): A crab fisher at work. The capture is done by pulling the male crabs out of their burrows by hand. (g): A *Callinectes*. This crab species is also common in the mangrove ecosystem. They are also captured and sold to the local markets (Photographs: D. Schories).

and females more frequently compared to traditional fishers. Modern crab collectors enter the mangrove forest with power boats and work in large groups of up to 25 people (Glaser 1998, Diele 2000). Due to a declining stock adjacent to their villages they began to exploit areas that were previously used only by the traditional fishers. Consequently a conflict between the two user groups arose as traditional fishers are concerned that their future yield is threatened. This concern is because of the indiscriminate catch by the modern group. With their powerboats, modern collectors have now started to exploit coastal regions outside the Caeté estuary.

DISCUSSION

The coastal geomorphology of the area discussed above represents a typical tidal allochthonous estuary. It is comparable to other mangrove areas described in the literature, e.g., Kjerfve & Lacerda (1990), Schaeffer Novelli *et al.* (1990), Spalding *et al.* (1997), Bunt & Stieglitz (1999). The coastline is marked by dunes and fossil cheniers and followed by mangrove vegetation with interspersed salt marsh. A small fossil bluff marks the boundary between the coastal plain and the upland. The distribution patterns of the mangrove vegetation indicate that there is a strong correlation between the hydrological regime, the microclimate conditions, and the topography. A distinguishable spatial pattern is seen by the variation of the mangrove tree heights. However, a species zonation pattern could not be detected.

The ecology of the mangrove ecosystem as a whole is still considered relatively undisturbed by human activities, but there is evidence of considerable and increasing local anthropogenic interference. Excessive woodcutting in the hinterland to expand agriculture has accelerated soil erosion in the catchment area of the river Caeté during the past few years. This has increased the sediment load in the river, and resulted in a silting-up of its bed which has made transportation by boat more difficult. Reports by local fishermen indicate a reduction in access to the Caeté river, which is the essential route of transport to bring the catch to the market at Bragança. Thus the shift in remote land-use patterns inflicts long-term damage to regional economic activities, including both crab and commercial fisheries. The increased sediment load of the river Caeté also decreases the depth of the euphotic zone within the water column. This leads to a reduction in phytoplankton production, which has a direct influence on the total primary production of the mangrove ecosystem.

Mangroves, in principle, can tolerate a high degree of excessive sedimentation stress. Nevertheless, at many locations within the mangrove ecosystem, trees have died off as their pneumatophores were covered by sediment, probably too quickly. As a result, in locations of good access, the local fisherman use the dead tree trunks as construction material for the maintenance of their fishing traps. Through the extraction of this first natural "coastal barrier", the mangrove hinterland is more vulnerable to impact by wave action.

In addition to the increase in sedimentation, the construction of roads has resulted in major changes to the natural mangrove vegetation. The roads have not only modified the local hydrodynamic regime but also facilitated easier access to the mangroves. Due to the first factor large numbers of trees died, and the second caused a shift in the traditional type of woodcutting. Selective cutting prevailed in former times, but because of the better accessibility via the road clear-cutting of mangrove areas has increased. Such twofold deteriorations of mangrove areas are well known from other parts of the tropics (Eusebio *et al.* 1986, Ellison & Farnsworth 1996, Pearce 1999, Thia-Eng *et al.* 2000).

Strong interconnections between the well-being of mangrove ecosystems and human acitivities exist in the Bragantinian coastal region. Such kinds of linkages have also been observed and described for other mangrove ecosystems, such as in Pernetta (1993), Rönnbäck (1999), Dahdouh-Guebas *et al.* (2000). The income of the rural population in the region depends on the natural resources of the mangrove area in the first place. Presently, the economy is based on the primary production sector. The town of Bragança has a local central supply function for the surrounding countryside. Thus the Bragantinian coastal area can be described as a raw-material producing peripheral region with a high diversity of income sources especially within the rural population.

Important factors for the economic wealth of the rural population are the distance to the urban market and the connection to the transport network. Increasing proximity to the urban center follows a decline in income source diversity. In the urban and "near-urban" areas households tend to be more specialized, presumably in an effort to capitalize on larger markets.

In rural locations, particularly the poorer households protect their incomes through a diversification of their occupational options. Taking advantage of their greater proximity to the surrounding natural resources, this group tends to use ecological riches and temporary/seasonal opportunities provided by the natural environment. This generates a higher number of occupations per household and greater seasonal differences in occupation and income source and leads to a greater dependency on the well-being of the mangrove ecosystem.

The communities on the eastern shore of the Caeté river, however, lack a sufficient transport network to the city and are not well stocked with mangroves. As revealed by a socio-economic rural census, this population is dependent on a wider range of income sources derived from the surrounding ecosystem.

This is not valid for places with unfavorable local environmental conditions. In such areas the rural population may have limited income generation options. As a case in point, the fisheries village of Vila Bonifacío is almost entirely dependent on the seasonal income fluxes by fish landings due to limited possible alternatives; these are described in detail elsewhere (Krause *et al.* 2000). Thus the population of such villages is exposed to socio-economic risks to a greater extent than rural villages closer to Bragança.

The entire Bragantinian coastal region experiences a substantial population growth. Because of the lack of alternative livelihoods, increasing pressure on the natural resources of the mangrove system is to be expected, especially by further intensification of the fishery efforts. Uncontrolled settlements in the coastal area will also contribute to a destruction of the mangroves.

CONCLUSIONS

This paper is the first geographic characterization of the Bragantinian coastal region in the State of Pará, northern Brazil, which is a part of the world's second largest mangrove ecosystem. It is focused on the natural environment and the situation of the adjacent rural communities based on stock-taking between 1997 and 2000.

We have found that the ecology of the Caeté ecosystem as a whole can be still considered tolerably undisturbed by human activities, but we point out that there is evidence for a considerable increase in remote and local anthropogenic interference. Land clearing in favor of agriculture has accelerated soil erosion in the catchment area of the River Caeté. This has caused damage to the mangroves and increased silting-up of the river Caeté, which forms an important transport link between the primary producers and their central market.

The income of the primary producers depends on the natural resources of the mangrove area in the first place, but also on their location with respect to access to the mangroves and the distance to the main market in the city of Bragança.

The considerable population growth in this region, together with the lack of alternative livelihoods, result in a greater spatial competition, affecting the ecological integrity of the coastal region and puts increasing pressure on the natural resources of the mangrove system. Expansion is expected. This is especially true for the conversion of and further intensification of the fishery efforts. Further destruction of the mangroves is expected to occur through uncontrolled settlements and the growing tourist recreation areas on beaches.

The main mechanisms which control the allocation of the mangrove resources within this region are decisions taken by local individuals. Particularly the identification of the latter is crucial for the development of a general plan for a sustainable management of the coastal zone.

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