Journal of Coastal Conservation 8: 97-102, 2002

Implications of mangrove dynamics for private land use in Bragança, North Brazil: a case study

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Abstract. This work analyses effects of recent variations in the tidal inundation frequency in a mangrove ecosystem in the Bragança peninsula, North Brazil, and its implications for land occupation and use. Field data, time series of remote sensing images and local legislation were analysed focusing on the potential socio-economic impact of a changing environmental setting due to a rise in relative sea level. In the investigated period (1972-1997), vegetation changes along the coastline indicate net losses of mangrove coverage. In the central part of the peninsula, a topographically higher herbaceous plain constituting part of a farm presents an active progression of mangrove forest into an area previously dominated by grasses and herbs. This area measured 8.8 km^2 in 1972 but was gradually reduced to 5.6 km^2 in 1997, while progressively replaced by a monospecific stand of the black mangrove, *Avicennia germinans*. A linear extrapolation indicates that the elevated plain may be completely covered by mangrove by 2035. Current Brazilian legislation prohibits the extraction of mangrove trees without an officially approved management plan. Thus, the usable area of the farm has suffered a reduction by ca. 36% over 25 yr and we predict that it could be entirely replaced by mangroves in the next 35 yr. In this case study, legislation and ecosystem characteristics are analysed and a management plan discussed which could represent income alternatives for affected resource users at the local and regional level.

Keywords: *Avicennia germinans*; Legislation; Sea-level rise; Wetland.

Abbreviation: GPS = Global Positioning System.

Introduction

Mangroves, as other coastal wetlands, are considered highly susceptible to sea-level rise (Gornitz 1991; Boorman 1999). Their extent is governed by tidal exposure and depends on the balance between sea level and sediment accumulation (Chapman 1960). Thus, a relative sea-level rise can result in both a mangrove retreat near the shoreline and a landward migration as a result of the increase in inundation frequency (Hanson & Maul 1989). Similarly, inland vegetation on elevated mud flats undergoes adjustment in its boundaries, since mangroves migrate to higher locations and invade these areas (Cohen unpubl.).

The Brazilian coast possesses the world's second largest mangrove region, estimated to cover a total area of 1.38 million ha along a coastline of approximately 6800 km (Kjerve & Lacerda 1993). The most exuberant mangrove habitats are found in North Brazil, where similar geomorphological features caused the development of analogous biological units with a common fauna and flora and similar patterns of resource exploitation (Szlafsztein et al. 2000).

Tide records obtained over the last 50 yr show a general rise in relative sea level along the Brazilian coast; Pirazolli (1986) reported a rising trend at four locations for the period 1950-1970. Studies in the Southeast region also indicate a rise since 1960 (Mesquita & Harari 1983; Mesquita & Leite 1985; Silva & Neves 1991; Silva 1992). Based on a time span of ca. 20 yr ending in 1968, Aubrey et al. (1988) reported rates of relative sea-level rise along the Brazilian coast from 0.3 to 3.6 mm/yr.

Muehe & Neves (1995) indicated that the high tidal amplitude and the low gradient of the rivers in North Brazil makes them particularly sensitive to sea-level rise. This would significantly increase the tidal propagation into rivers, probably influencing their sediment budget and salt content. Large-scale destruction of mangroves at the oceanic front in North Brazil and French

Guyana has been reported by Nittrouer et al. (1991) and Proust et al. (1988), respectively. Extensive shore erosion along the Brazilian coast has also been reported (Muehe & Neves 1995 and references therein). Since the evidence is still not sufficient to relate these observations to sea-level changes, these authors have recommended to intensively monitor determined vulnerable coastline sectors. One of the suggested locations is Salinópolis (Pará), which suffers the effects of severe erosion, as already described by Franzinelli (1982). This site is situated at ca. 100 km from the Bragança region, where the present study was carried out. The general characteristics of this area make it representative of the extensive mangrove belt near the Amazon mouth (Szlafsztein et al. 2000).

One of the ways to attempt minimizing present and potential impacts of sea-level change on ecosystem and human activities is the implementation of a coastal management plan for the region. This requires the analysis of the past and present state of the natural and man-made system in order to be able to predict its evolution under changing environmental conditions (e.g. sea-level rise) and/or different utilization scenarios. Additionally, local legislation regulating land occupation and resource use must be analysed and if necessary adapted, in order to be able to develop suitable strategies for sustainable system utilization.

The present work analyses effects of recent variations of tidal inundation frequency in a mangrove ecosystem near Bragança and their implications on land occupation and use. Field data, time series of remote sensing images and local legislation were analysed focusing on the potential socio-economic impact of a changing environmental setting.

Study area

The Bragança peninsula (166 km^2) is situated in a mangrove region ca. 200 km southeast of the Amazon estuary (Fig. 1). The system is a riverine/fringe mangrove, characterized by macrotides of ca. 4 m range

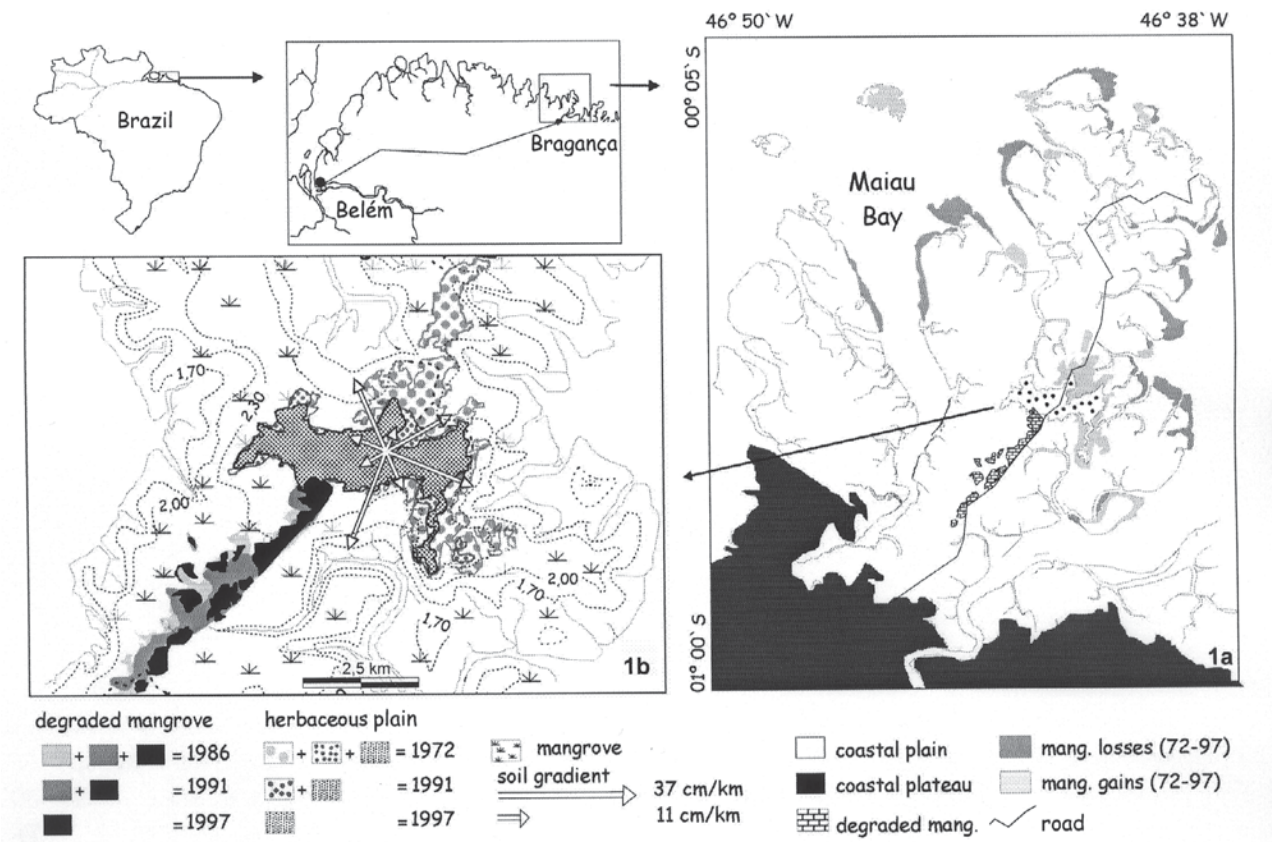

Fig. 1. Study area on the Bragança peninsula, State of Pará, Brazil, indicating (**a**) net gains and losses of mangrove coverage along the coastline for the period 1972-1997, the elevated herbaceous plains in the inner part of the peninsula and (**b**) its central area with the transition between herbaceous vegetation and mangrove forest and the development of a degraded area.

(Cohen et al. 1999). Sediment transport is highly dynamic, with areas of rapid mud erosion and deposition. The Caeté river – which is ca. 100 km long – drains upstream from the mangroves ca. 3000 km^2 of hinterland (Schwendenmann 1998), and its discharge ranges from ca. 180 m^3/s (rainy period) to 0.3 m^3/s (dry season).

The whole region of Bragança (hinterland, city and mangroves) has 93.705 inhabitants (Anon. 2000). It shows little industrial development and is moderately used for agriculture and cattle farming. In rural villages, about 68% of households derive monetary income from the mangrove ecosystem (Glaser unpubl.). Mangrove timber is predominantly used to fire kilns in brickworks (Berger et al. 1999). As part of the government's policy of facilitating access to coastal resources, ca. 20 yr ago, a road that connects the city of Bragança with Ajuruteua beach was constructed (Fig. 1). Besides facilitating tourism development, this road permits the transport of mangrove products to local and regional markets.

In the central part of the peninsula, a topographically higher herbaceous plain surrounded by mangrove, and constituting part of a farm, was selected for the investigation of its recent evolution. This area has been used since at least 1870 and until recently as grassland for water buffaloes and other bovines, while today these activities have been mostly abandoned. The 80-yr-old farm owner stated that the mangrove has been invading the herbaceous areas since he was a young man. Thus, although this work presents quantitative data only for the last 25 yr, there is evidence suggesting that this process began several decades ago.

Material and Methods

A time series of satellite and aerial images for the period from 1972 to 1997 was analysed focusing on the identification and quantification of vegetation coverage changes. A mosaic of airborne RADAR images (Band X) taken in April 1972 was released by the Federal University of Pará. Five LANDSAT-TM5 images acquired on August 1986, 1988 and 1997, September 1990 and December 1991 were obtained from INPE (National Institute of Space Research, Brazil). Topographical and hydrographical information previously obtained by Cohen (unpubl.) was used. Visual observation, photographic documentation and GPS measurements were used to determine typical plant species, their geographical location and characterize the main geobotanical units in the peninsula. The sources for the analysis of legislation and environmental regulations are cited in the references.

Results and Discussion

Changes in vegetation over the last 25 years

Vegetation changes along the coastline indicate net losses of mangrove coverage for the period 1972-1997 (Fig. 1a). The central area (Fig. 1b) is flooded only during the highest spring tides and presents evident signs of an active transition between herbaceous vegetation and mangrove forest, with coexistence of the grass *Sporobolus virginicus* and the herb *Sesuvium portulacastrum* as well as small (0.5-2 m) *Avicennia* (black mangrove) trees (Behling pers. comm.). The progression of the mangrove front in this area is highly dynamic and can be clearly followed over the 1972-1997 interval. The open marsh area consisted of 8.8 km^2 in 1972 and had shrunk to 5.6 km^2 by 1997, i.e. decreased ~36% in 25 years, replaced by a monospecific stand of *Avicennia.* Mangrove invasion closely followed the topography, being more pronounced in the area with a lower slope (Fig. 1b). The present boundary between marsh and mangrove corresponds to an inundation frequency of ca. 40 days/yr, with *Avicennia* trees 1 to 5 m height. The former mangrove/marsh boundary in 1972 is now inundated for ca. 60 days/yr and presents trees of 8-10 m height. Marsh areas were converted to percentages of the 1972 value, which was taken as 100%. Regression analysis indicated a linear, highly significant ($r = 0.98$, $n = 7$, $p < 0.001$) relationship between these percentages and time. A linear extrapolation (Fig.

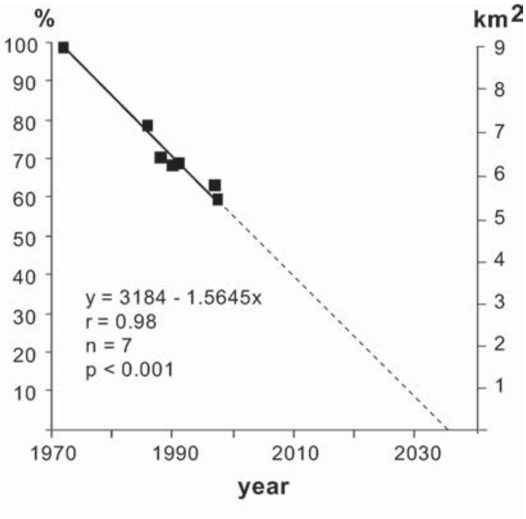

Fig. 2. Progression of the mangrove front in the central Bragança peninsula expressed as decrease of the extension of the herbaceous plain, whose areas for the interval 1972-1997 were converted to percentages of the 1972 value, taken as 100%.

2) indicates that the herbaceous vegetation would disappear around 2035, probably to be replaced by an *Avicennia* forest.

This assumption is further supported by the extrapolation of the advance of the topographical mangrove/marsh boundary, which corresponded to a height of 2.4 m above m.s.l. in 1972 and of 2.5 m in 1997. This topographical change in the vegetation boundaries indirectly suggests the magnitude of the relative sea level rise expected for the area, which assuming linearity, would correspond to a rate of increase of 0.4 cm/yr. At this rate, the limit between both habitats would be ca. 15 cm higher in 2035 than in 1997. Thus, since the highest point in this sector is ca. 2.60 m, most marsh plants would have disappeared by that time and be replaced by mangroves.

These extrapolations are compatible with predicted estimates of sea-level rise. According to Titus & Narayanan (1995) there is a 1:1 possibility that greenhouse gases will have produced a sea-level increase of at least 15 cm in the year 2050, 35 cm in 2100, and 80 cm in 2200. Moreover, there is a 1:40 chance that this rise be 35 cm in 2050, 80 cm in 2100, and 300 cm in 2200. A projection of the first estimate would imply that by 2035, the sea-level might have risen about 10 cm compared to 1997. Thus, it seems realistic to assume that the advance of mangrove forests towards higher locations will significantly influence land use.

Current legislation related to mangrove regions

The Brazilian Federal Constitution declares the use of property subject to a social function, such as e.g. the 'protection and conservation of the environment' (Anon. 1988). The Federal Forestry Code (1965) established the 'permanent preservation' of all vegetation forms which contribute to dune fixation or mangrove establishment, which has been interpreted as a prohibition of the use of any components of mangrove flora. In 1988 the 'National Plan for Coastal Management' (Anon. 1992) elaborated criteria for rational resource utilization in the coastal zone, prioritizing the conservation and protection of wetlands (Leme Machado 1993).

The Laws 6938/81 and 7661/88 (Anon. 1992) declare as punishable criminal offence all activities leading to the degradation of 'ecological reserves'. Since sustainable management of wood extraction by definition should not degrade the ecosystem, then this regulation provides an opening for the transformation of current uncontrolled illegal mangrove wood extraction activities into controlled management. For landowners with mangrove encroachment problems on their land this also represents a way to develop sustainable legal forms of utilizing mangrove timber resources.

In 1999, the State of Pará declared the extraction of mangrove bush plants or trees illegal in all its territory (Anon. 2000b). The 'Organic Law' of the City of Bragança established that the Municipality can define protection areas, and may prohibit any kind of utilisation which may endanger flora and fauna in the coastal region (Anon. 1990). No such protection areas have been hitherto established in this region.

A decision support system of management

The farm in our research area is in a topographical setting, which under increasing inundation frequency contributes to mangrove establishment. The alternatives for commercial use are limited: crab density is very low in *Avicennia* forests and fishery is not possible due to the absence of deeper creeks. Moreover, pertinent legislation prohibits tree extraction, at least without an approved management plan. Thus, under the current interpretation of relevant legislation, the usable area of this private farm has fallen by ca. 40% in 25 yr and will probably disappear in the next 35 yr.

Mangroves play a crucial role in coastal dynamics, particularly under conditions of sea-level rise and they clearly must be preserved. However, ecosystem protection, reduced to the function of strict or partial prohibition of resource use, could cause unsustainable outcomes such as the disintegration of the economic strategies of rural households and consequent migrations of coastal populations to already overloaded urban areas. The state of Pará has had the highest urban growth in its history during the last decade (Anon. 2000).

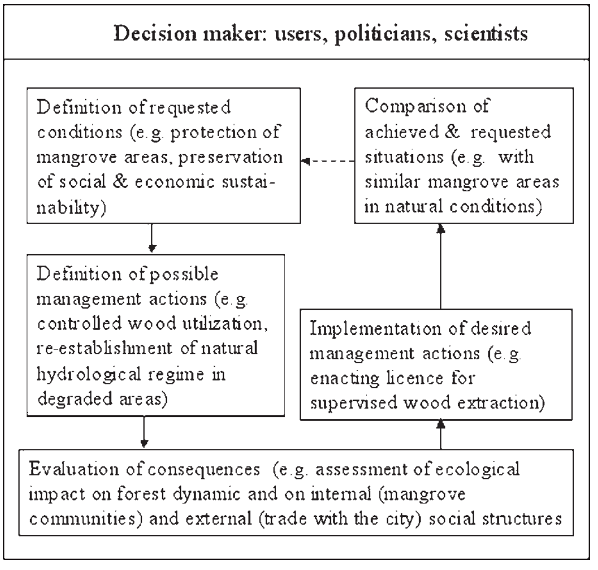

Fig. 3. Example of a decision support scheme, applied to a specific situation, combining mangrove protection and use.

Decision Support Systems (O'Callaghan 1996) provide an evaluation of ecological, economic and social implications of different management scenarios, as shown in Fig. 3 for this study case. Decision makers should include resource users, politicians and scientists to jointly define the requested systems conditions, such as the protection of mangrove areas and the preservation of the social and economic sustainability of a low-income population.

An explicit operational goal could be the definition of areas for forestry studies in the farmland and specific sectors of the central peninsula under controlled quantity, spacing and frequency of wood extraction. The study area offers interesting possibilities for a pilot project: Three quite different *Avicennia*-dominated forests are located in a relatively reduced area with a similar topographical setting: (1) the mature stand at the right road side could represent the control reference for the regulated wood utilization in (2) the new stand in the farm and (3) the regenerated stand in the previously clear-cut area. Selective wood extraction might have the same effect on the development of the mangrove forest as the natural self-thinning process (Berger & Hildenbrandt 2000). It occurs in all forest stands under development and is analysed and described for monospecific cohorts in detail (Londsdale & Atkinson 1982; Londsdale 1990; Quang 1994; Adler 1996; Guo & Rundel 1998).

The implementation risk of each scenario must be assessed considering the ecological impact on the forest development as well as the effect on the internal ('mangrove communities') and the external (trade with the city) social and economic structure. The former can be accomplished by using simulation models (Baker 1992; Bart 1995; Twilley et al. 1999). It must also be considered that mangrove vulnerability is not the same everywhere. Severe ecosystem degradation can be expected in case of wood extraction along the coastline, where trees and sediment are exposed to higher energy and thus to erosion. In less frequently inundated, low-energy areas such as the central part of the peninsula, mangrove vegetation will be more negatively affected by disturbances of the hydrological regime, as happened after the construction of the road Bragança-Ajurutea. (Fig. 1a). In order to facilitate tourism development on the beaches in the north of the peninsula, in 1974 a road was built across the mangroves. This constrained tidal inundation in some topographically higher locations, resulted in the death of mainly *Avicennia* forest over an area of an estimated 6 km^2 at the left side of the road (Fig. 1b, 'degraded mangrove'), while the right side apparently did not suffer any obvious impact. During, or as a consequence of, this process, the local population actively extracted wood from the degraded area. Analysis of available satellite images show a partial recolonization of this sector, reducing the degraded area progressively from 3.8 km^2 in 1986 to 2.9 km^2 in 1997. It is not clear whether this process responded to 'normal' forest dynamics or was accelerated by the increase in inundation frequency postulated as responsible driving force of the *Avicennia* invasion in the herbaceous plain.

Conclusions

If a controlled wood extraction were allowed in some parts of the farmland, the natural structure development of the forest would probably not be disturbed. The regulation of this activity could reduce the common practice of illegal, uncontrolled wood extraction in the mangroves of the region. Besides, simple management actions such as the construction of bridges at adequate sites along the road, could probably significantly accelerate recolonization in degraded areas by increasing inundation frequency. Although accomplishment of such plans seems straightforward, a careful comparison of the situations achieved with the initial aims is always necessary (Fig. 3, dotted arrow). If necessary, the whole process must be re-evaluated. This is in agreement with Meirelles (1993), who states that the Executive Plan of Brazilian municipalities is not static but dynamic, and has to be adapted, in a permanent management process, to new needs. It is probably at this level, where the greater potential for the integration of changing ecological and socio-economic settings resides.

Acknowledgements. This study is a result of cooperation between the Centre of Tropical Marine Ecology (ZMT), Bremen, Germany and the Universidade Federal do Pará, Belém, Brazil, under the Governmental Agreement on Cooperation in the Field of Scientific Research and Technological Development between Germany and Brazil financed by the German Ministry of Education, Science, Research and Technology (BMBF). (MADAM – Mangrove Dynamics and Management, Project number: 03F0154A) and the Conselho Nacional de Pesquisa e Tecnologia (CNPq).

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Received 7 June 2001;
Revision received 22 February 2002;
Final version received 25 July 2002;
Accepted 25 July 2002.
Coordinating Editor: F. van der Meulen.