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Co-evolving geomorphical and socio-economic dynamics in a coastal fishing village of the Bragança region (Pará, North Brazil)

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Abstract

In the area of a coastal fishing village on the mangrove peninsula of Bragança, State of Pará, North Brazil, coastal changes were observed by a beach profile monitoring programme between 1997 and 2001. The assessment allowed a subdivision of the region into four small coastal cells (1–3 km), partly exhibiting heavy erosion. A number of related socio-economic problems, such as loss of alternative income sources caused by the locally unpredictable erosion patterns were identified in three separate village sections. This results in a year-round dependence on seasonally low fishery incomes and increases the risk of poverty. Since limited options for action are available to the local population, different social groups have evolved different land use patterns, which in turn influence local coastal morphodynamics. Not only the hydrodynamic signature, but also the socio-economic organisation of a coastal community and the co-evolutionary path between these two variables thus indicate the state of a coastal system and the most promising policy actions towards sustainable coastal management.

1. Introduction

In numerous studies on beach morphodynamics, the site-specific hydrodynamic signature[1] is considered to constitute the main driving force for a coastal system. They appear to act as fundamental constraints on the development of a coast [1–5].

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[1] Following Short [5] the hydrodynamic signature is defined as the sum of all driving forces (wind direction & force, wave type and frequency, tidal amplitude, etc.) acting on a specific coastline.

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The temporal patterns of the pulsating driving functions (e.g. tidal amplitude, wind direction and wave forces), especially timing and magnitude, are crucial in the formation of coastal geomorphological patterns and structures. The hydrodynamic signature can therefore be understood as the common denominator, which determines the structure that develops in coastal systems and is, in turn, affected by it [4].

This article describes the co-evolution between human actions and strategies and coastal geomorphology in a mangrove ecosystem. Such tropical systems evolve in different spatial patterns according to the predominant impending geomorphic forces [1,6,7]. Natural beach environments, which commonly adjoin mangrove ecosystems, are shaped by the interactions between the biota, sediments and water according to their specific ecological and physical processes [8]. Additionally, they are influenced by human use [9–11]. In an earlier study, Krause [10] shows that beach morphology profile types along a mangrove ecosystem can differ greatly on a small scale (1–3 km), even if hydrodynamic signatures between sites are almost identical and demonstrates that this is due to the site-specific nature of human utilisation and its interaction with coastal morphodynamic processes and ecosystem elements, such as mangroves and dune vegetation. This correlates with the work of Mazda [12] who associates the decrease of natural coastal protection potential with human and tidal long-term impacts on mangroves.

The article's objective is to investigate in detail if, and in what way, site-specific beach morphodynamics and socio-economic structure interact within a traditional fishing village in a tropical coastal setting. These interactions result in the generation of opportunities and hazards. As our time series of beach profiles were gathered over a 4 year-period, it covers a sufficiently long temporal range so that the link to socio-economic dynamics is feasible. Thus, the impact of coastal morphodynamic processes on residential distribution and on the development of local social infrastructure can be shown and the repercussions of human coping strategies with erosion events on the future likelihood of such events assessed.

2. The Bragança coastal region and the village of Ajuruteua (Pará, North Brazil)

Sudden, event-like erosion in Parà, North Brazil, is a frequently recurring and important component in the livelihood dynamics of the coastal population. In the following section, the iterative co-evolution [13,14] of socio-economic and natural dynamics of a coastal mangrove area is discussed for the case of the coastal village of Ajuruteua in the municipality of Bragança in the State of Pará (North Brazil).

The population structure of the municipality of Bragança is characterised by high demographic growth, particularly in the urban and coastal areas. As land scarcity increases and land quality deteriorates in agricultural colonisation areas further inland [15], the coast of Pará has increasingly become the destination for migrants from these regions and from the North-East of Brazil [16]. The mangrove resources of the peninsula adjacent to the town of Bragança in our research area (Fig. 1) are

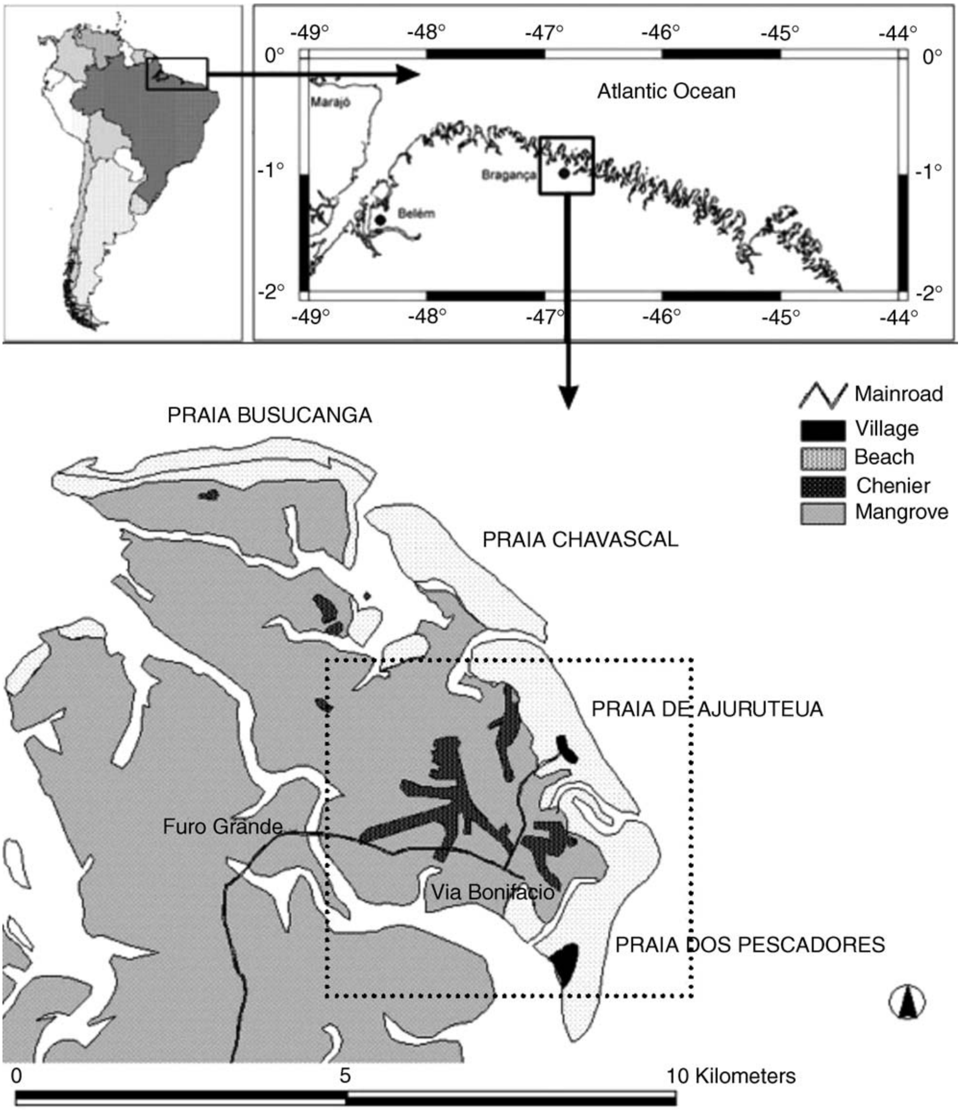

Fig. 1. Location of the research area in North Brazil in the State of Pará. The dotted square in the lower figure shows the location of the coastal fishing village Ajuruteua on the North coast of the 180 km^2 mangrove peninsula at the town of Bragança. Source: Krause [18].

currently being used by over 80% of a population of about 15.000 people in 21 rural communities [17,18]. The region has a high percentage of adolescents. In the year 2000, over 63% of the population were under 20 years of age, in contrast to a national average of 28% [19]. Moreover, in 1997, 13% of rural households here were female-headed [20] which indicates a considerable importance of female incomes for the rural household economy. Main economic activities of the area's rural coastal households are agriculture with a high number of small landholdings, crab collection and artisanal fishery [18,20,21]. Considerable residential mobility is common. Only about 44% of current household heads of the rural Bragança coast were born in their current community of residence.

The village of Ajuruteua is part of the research area of the MADAM (Mangrove Dynamics and Management) project on the mangrove peninsula of Bragança [17,18]. This peninsula is covered by about 180 km^2 of mangrove forest and bordered by the estuaries of the Caeté and the Tapera-Açú rivers, which have average tidal ranges between 3 and 5 m [18]. The area belongs to the meso-tidal water regime, classified as "tide dominated allochthonous" after Thom [1]. The peninsula is predominantly covered by three mangrove species: *Rhizophora*, *Avicennia*, and *Laguncularia* and the general local landscape classification is "*Região Bragantina*" which is part of the "*Amazon Oriental*" of North Brazil [18].

The village of Ajuruteua was selected because of its spatial seclusion at the northern point of the Bragança peninsula. Access to the village is only by boat or on the paved road which crosses the peninsula in a North–South direction [18].

Ajuruteua consists of three separate village sections (Fig. 2). Each village section is spatially separate and has specific hydrodynamic signature(s).

1. *Praia*: a beachfront location with considerable tourism development spearheaded by outside entrepreneurs.
2. *Vila dos Pescadores*: A beachfront location, prone to erosion with a majority of artisanal fishing families.

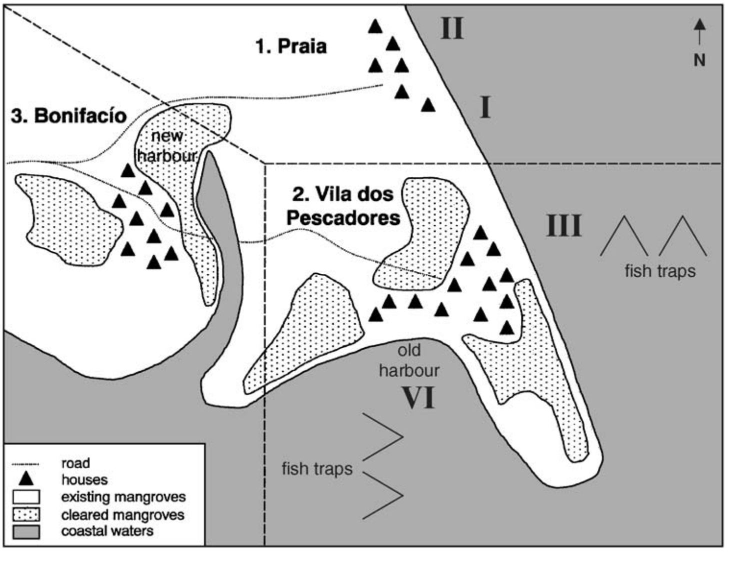

Fig. 2. Schematic map of the three village sections of Ajuruteua. Each village section exhibits specific hydrodynamic signature(s) indicated by roman numerals as different coastal cells.

3. *Bonifacío*: A tidal channel location, more recently settled by better-off migrants from the village section 2 (*Vila dos Pescadores*).

The formation and transformation process of the entire village has been driven by the road construction in the mid-1970s, which has facilitated access to this coastal area.

3. Methodology

In the spatial assessment of a socio-economic structure, it is difficult to determine a systemic reference state. Since social changes can occur at various temporal and spatial scales, results will vary according to the selected scale (e.g. [4,22–27]). Consequently, the definition of the spatial and temporal scale of geomorphological processes is the most relevant issue to highlight the dynamics of the coastal system. We therefore have set the proviso that statements about ecological, geomorphological, social or economic systems are made for defined time periods only.

Of the various driving forces that act upon the mangrove coastal ecosystem [28–31], sedimentation and erosion dynamics and the associated socio-economic dynamics were addressed at a small geographic scale. Using geographical and socio-economic methods in jointly agreed geographical boundaries [32], an interdisciplinary approach to the identification of co-evolving patterns of coastal dynamics in mangrove areas, the current coastal changes and their socio-economic implications was developed.

Socio-economic data was collected:

1. In a household census of 21 villages in over 1700 interviews, the "community-based statistical survey" (CBS) in 1997/98 [20].
2. In 20 semi-structured interviews covering the key themes of erosion, resettlement and local strategies in the village sections of (2.) *Vila dos Pescadores* and (3.) *Bonifacío* in 1999. In this pilot study, 20 interviews of approximately one hour duration each, were conducted by four members of a Brazilian student group and the second author. Each interviewer conducted four interviews at the residents' home in a subsection of the village so that residents of all areas of *Vila dos Pescadores* and *Bonifacío* were interviewed. All interviewers subsequently conducted a group discussion of their results.
3. In 1999 and 2000, three community meetings were jointly organised by the two researchers and the local rural labour union in order to identify local problems and to plan a technical assistance project for mangrove-dependent fishing communities. In these meetings, community perceptions of local geomorphological dynamics and local socio-economic strategies and reactions were discussed. In order to address gender-specific issues, one of these community meetings was held exclusively for women.

On the geomorphological side, beach profiles in the populated area were conducted. Data collection was carried out at five locations along the beaches of

Ajuruteua between October 1997 and June 2001 on about a fortnightly basis [10]. By employing a long-term beach profile monitoring programme, the principal properties of local coastal dynamics were assessed. Similar investigations were successfully performed in many other areas throughout the world (e.g. [11,33–37]). Such studies have shown, that the data on geomorphological changes of beaches over time allows a good estimation of the speed and direction of the ongoing coastal processes (e.g. [5,10, 35, 38–43]).

As infrastructure of the Bragança coastal region is rather frail [18], straightforward measurement tools were essential. For the repeated measurements of beach profiles over time, a rather simple method was chosen as described in Emery [44] and Krause [45]. Two wooden measurement poles were connected with a rigid string of 2 m length. Starting at a known benchmark position behind the first dune ridge, these poles were then placed subsequently along a shore-normal transect until the sub-tidal platform was reached. The observer viewed the top of one pole and levelled it to the height scale of the other in reference to the horizon. By doing this, height differences were measured for every 2 m step. Summing up the differences with respect to the benchmark position results in a beach profile. This methodology has the important potential of allowing for high temporal and spatial sampling at tropical environments with few technical resources. The error investigations in Krause [45] have shown, that this method is appropriate and gives satisfactory results on the beach morphodynamics.

4. Results

Ajuruteua village has three different socio-economic settings which will be briefly outlined below. Fewer than 3% of households engage in any kind of cultivation and fisheries is the primary income source of the village. 18% of households belong to the fishing colony, 18% to the local football club and 33% to the Catholic Church as well as 6% to the Evangelical Church. Only 8% are organised in the local community association [46].

1. *Praia*: There were 166 households in 1997 at this beachfront location which has been the main focus for beach tourism of this region. It has attracted a majority of better-off new residents and absentee owners from other areas of the State and the North-East of Brazil since the access road was completed in 1983. The first arrivals on this beach, the artisanal fishers have today come to reside in a "second row" of houses, ousted from direct beach access by better-off tourism entrepreneurs and land speculators. Due to additional earning options from tourism and the investments of recently migrated tourism entrepreneurs, only 55% of residents of this village section depend on artisanal fishery and the number of income sources per household is, with 1.66 income sources per household somewhat higher than in the other two, more traditional village sections.

2. *Vila dos Pescadores*: This oldest part of the village is today inhabited by the poorest artisanal fishers of the village and old people. The area is subject to heavy erosion. With about 300 houses in 1987 [16] and 119 houses in 1997, this village

section has suffered a continuous population exodus towards the better-protected village section of *Bonifacío* over the past decade. In 1997, 73% of resident households engaged in artisanal fishery. With an average of only 1.43 income sources per household, fishery predominates as the main household income. This village section has the most dilapidated and low quality wooden housing with all the signs of low-cost impermanence and the most neglected social infrastructure among the three village sections. Here we also find the partially degraded wooden village school, and a number of households without access to fresh water due to saline intrusion into their shallow, hand-dug wells.

3. *Bonifacío*: This village section only started forming in about 1995. It has turned into the recipient of the relatively better-off and better-networked artisanal fishing households. There were only 74 houses in 1997 but population has been continuously moving in from other parts of the state and from *Vila dos Pescadores* (village section 2) where erosion has been most extreme in the past. 81% of resident households in this village section are commercial artisanal fishers and the number of income sources per household is 1.49. Over the past decade, a large number of substantial wooden and part-concrete houses have been erected here by migrants from section 2 (*Vila dos Pescadores*). In 2001, a new health centre and school were erected with public funding. The village leader resides here and, over the past decade in the wake of repeated erosion events of the *Vila dos Pescadores* section of the village, associations and village clubs have moved into this section.

4.1. Beach morphodynamic patterns

The four-year beach profile monitoring programme identified of four spatial cells as coastal management units. Three of these cells can be directly correlated to our three village sections, the fourth is located more northwards along the coastline and is part of village section 1 (*Praia*) of Ajuruteua. Cells are small, between 1 and 3 km in extension each and are characterised by specific dynamic behaviour and human utilisation patterns. Only one of the units (cell 1, village section 1, *Praia*) had a stable coastline during the four years of observation, where a few weekend homes were erected behind the first dune ridge. In cell 2 immediately north of this, (village section 1, *Praia*), housing was erected on the dune ridge in the wake of increasing tourism, with large resulting damage to the natural vegetation. Here, erosion predominantly occurs on the dunes. Cells 3 and 4 are both located in village section 2 (*Vila dos Pescadores*). Cell 3 encompasses the coastline bordering the Atlantic Ocean and shows a mean annual retreat up to 10 m [10]. Along the shorefront, fossil mangroves are exposed on the beach, which indicate the former extent of the coastline. The most important reason for increased erosion in this area is the human impact of clearing the adjacent fringing mangroves. The exposed fossil mangroves on the beachface have created a semi-stable ridge structure on the upper intertidal zone. The adjacent backshore is subject to flooding at extreme spring high tides, thus creating washover fans, which cover the entire area of the village. During other time periods, aeolian sediment transport initiated by the trade winds carries the fine sandy sediments from the beachface into the residential areas. This mobile sand directly affects the village. It covers gardens and roads and is constantly swept into the houses.

In cell 4 (old harbour of village section 2), the construction of large fish traps has enhanced erosion at the shoreline [10]. These traps artificially capture sand and create sandbanks and thereby increase current velocities of the tidal channel. The latter can also be detected in occasional satellite images (Fig. 3) and historic aerial photographs. The regression rate described above is exceeded at the local old harbour, which is rather protected from the incoming waves, but subject to the influence of tidal currents. Here the coastline is cut back annually by up to more than 20 m (Fig. 4). Next to the strong tidal currents, two other major reasons for the observed strong retreat were identified during the monitoring programme:

(a) the removal of village-adjacent mangroves for domestic cooking fuel and construction material, and
(b) the erection of large fish traps (isosceles triangles, approx. 200 m side lengths, locally called *currais*) in the tidal channel.

Fish traps are constructed during the rainy season on sandbanks along the estuary of the river Caeté. *Currais* are used throughout the Bragantinian Region [47] and are commonly assembled from mangrove wood. Due to the high sedimentation rates

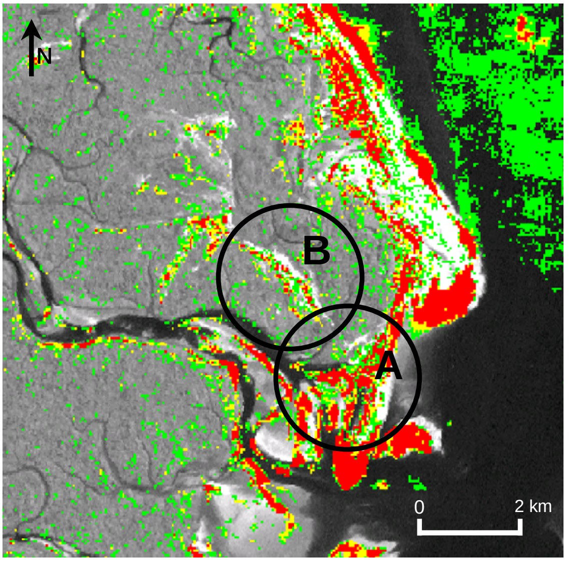

Fig. 3. Change detection analysis from two satellite images (Landsat TM 7). The resulting image matrix provides an aggregated fuzzy membership value scaled between 0 and 1 for the class 'changed between 1991 and 1999'. The red areas indicate an intense change in the landscape of 0.9 to 1.0, followed by yellow coloured intermediate land cover change between 0.8 to 0.9 and green coloured areas of moderate change between 0.7 to 0.8. The grey shaded areas highlight landscape stability. This analysis reveals the effects of coastal dynamics by exposing the highest change rates over a period of 10 years. This is especially obvious in the two hot spots of change: The village section 2 (*Vila dos Pescadores*) (A) and site B the new settlement of the well-off members of this community (village section 3, *Bonifacío*).

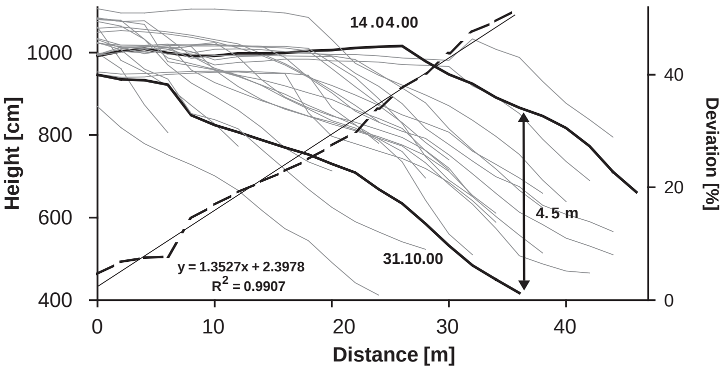

Fig. 4. Beach profile series between 19.12.1999 and 12.1.2001 at the location of the old harbour of the village section 2 (*Vila dos Pescadores*). On the left, the beach height difference of the profiles from the benchmark position to the seashore is expressed in cm with an arbitrary positive value and displayed with a 100-fold exaggeration factor. The distance from the benchmark is given in meters. As one example for the strong regression rates at this location, the profiles on the 14.04.2000 and on the 31.10.2000 are marked in bold. In this period, the beach was cut back roughly 20 m and lost 4.5 m in height at the seaward limit. The deviation shows the correlation of height loss in percent between these two profiles, which is displayed here as the steep linear trend.

following the construction of *currais*, the newly accumulated sandbanks have stabilized and developed into large-scale geomorphological elements of this coastal zone.

4.2. Impacts on local life and livelihoods

A set of erosion-linked socio-economic risks was identified by interviewing affected local residents. The strong erosion rates along the shorefront of *Vila dos Pescadores* have forced local people to repeatedly remove and reconstruct their housing. Interviewees reported this to have occurred up to five times in current residents' lifetimes. Another serious risk to local livelihoods exists in the loss of fishing boats in the not uncommon surprise "overnight flooding". Here, within one tidal cycle, several meters of the shorefront can be removed, leaving unlucky residents without their housing or means of production.

Settlements in beach and mangrove areas are legally forbidden, but currently not effectively prevented by the Brazilian authorities [48]. Ajuruteua residents therefore have no territorial rights, no post-erosion compensation claims and thus very limited options to move elsewhere. Resettlement costs for coastal households affected by erosion are borne entirely by the affected households. Some of the poorest families in the more erosion-prone location of *Vila dos Pescadores* (village section 2) thus explained their failure to resettle before the advent of erosion by their inability to afford the nails to reassemble their wooden habitations elsewhere.

A clear failure to invest in permanent structures or plantations is visually evident in all of Ajuruteua village and is reflected in the lower number of income sources per household. In all three sections of Ajuruteua village, income source diversity is lower than the regional average of 1.9 income sources per household.

A local failure to invest available surplus into permanent infrastructure is also evident. It is shown by contrasts such as the presence of satellite dishes on huts of the very lowest quality. That the latter is a feature of Ajuruteua village but not of the communities further inland in this region suggests a causal link with erosion. This was confirmed by our interviews where statements as ‘‘It will all be washed away anyway, nobody knows what the sea will do’’ expressed a high degree of fatalism [20]. Supported by a number of interviewee and public meeting statements to this effect, we thus argue that the current local inability to predict the temporal spacing and degree of likely impact of erosion events is a major reason that locally available surplus is directed away from investment into future household productivity. Moreover, the neglect of community infrastructure (maintenance of schools, roads, electricity poles) in section 2 (*Vila dos Pescadores*) is a risk-avoidance strategy which residents themselves also clearly link to their inability to predict sediment dynamics. Increased health risks are generated by reduced or absent investments into sanitation and waste collection, which has clearly a lower standard in *Vila dos Pescadores* and *Praia* than further inland in the region [20]. The regular, village-wide dispersion of garbage during high tides, due to the absence of any collection structures or systems is a striking expression of this hazard to health and safety which is directly linked to the low degree of local predictability of erosion.

4.3. Co-evolving geomorphological and social dynamics

In *Vila dos Pescadores* locally unpredictable coastal erosion events have lead to a loss of incomes by the destruction of permanent plantations, e.g. coconut and other fruit trees [20]. Local residents themselves attribute their failure to invest in agri- or horticulture to their inability to estimate future erosion events and therefore the risks to permanent crops. Particularly households who depend on female income earners are affected, since agri- and horticulture are predominantly female occupations in the region. In contrast to communities further inland, the beach village of Ajuruteua has seasonally and occupationally much less diverse sources of income and higher rates of occupational change among residents [20,21]. This low income source diversity manifests itself as a year-round dependence on seasonally low fishery incomes and results in increased poverty risks and decreased economic stability at the household level.

A spatial analysis of settlement patterns reveals a tendency for relatively better-off people from *Vila dos Pescadores* (village section 2) to move further inland into the less erosion-prone areas of *Bonifacío* (village section 3). The remaining local population copes badly with the adverse natural conditions, as house constructions along the coastline are of poor quality, due to the risk of overnight loss by erosion events. The relocation of the wealthier population into the adjacent coastal hinterland of *Bonifacío* where better-constructed houses were erected has been accompanied by the removal of large patches of mangroves. This may lead to expulsion, if the State legislative objective of non-use and non-settlements in mangroves [48] were to be enforced.

More importantly, mangrove deforestation in the wake of resettlement increases future erosion risks at the newly settled location. The clear-cutting of mangroves has led to an increased retreat of the coastline, especially at the old and the new harbour, as the sediment trapping capacity of the mangroves is lost. This process was further intensified by the removal of the mangrove roots along the old harbour front to provide better access for boats, since the active excavation of the trunks augments erosion [10]. This has resulted in a negative sediment flux budget as sediment is drained out of the nearshore coastal sediment system and followed by an intensification of erosion along this strip of coastline.

In addition, the large-scale sand banks that are created by the large fish traps in the tidal channels have reduced shipping access to the town port of Bragança, and fishermen relate lower catch to the reduced depth of the silted-up river.

5. Discussion

5.1. Negative co-evolutionary potential

Our case study shows that the hydrodynamic signature alone does not necessarily explain beach morphodynamics. The key to the understanding of the morphodynamic system are those socio-economic strategies which interlink with local geomorphologic processes. Our case study shows a strong affiliation between geomorphological changes, their local predictability and socio-economic structure and dynamics.

Socio-economic stability is positively correlated with income diversity, especially for poor households. Several studies [20,49–52] show that vulnerable, poorer households utilise income source diversity as a risk reduction strategy. Occupational and income source diversity assumes a stabilising function in conditions of high livelihood risks, which are common for the poorer populations of rural tropical regions. The stabilising function of income diversity is also recognised in business and personal investment strategies, which commonly use portfolio diversification as a risk minimisation strategy. We have demonstrated in our case study that rising incidence falling and local predictability of extreme beach morphodynamic events reduce the degree of income diversification realised by potentially affected coastal residents.

Natural sediment relocations change the spatial properties of the mangrove system. Human use of the coastal area is also intensified by immigration. Immigration generates a neo-traditional social structure [26], which is mirrored in modifications of the original spatial distribution of residences and residents' lack of knowledge of coastal dynamics. The "ecological illiteracy" of recent migrants causes undesirable back-loops between natural sedimentation dynamics and human strategies such as the deforestation of coastal areas prone to erosion, which increases erosion and with this likelihood that the relocation of residents becomes necessary [53]. Thus, economic and social structures and dynamics are not only generated by the strong instabilities of this coastline, but they also generate additional geomorphological instabilities to which adaptive socio-economic strategies will be required in future. In this sense, there is negative co-evolutionary potential between geomorphological and socio-economic structures.

5.2. Positive co-evolutionary potential through education and information

The village section of *Bonifacío* is situated adjacent to the developing tourist resort of *Praia*, which is considered one of the best beach areas of the State of Pará [10,18]. The high local eco-tourism potential may be the best option for future local development. However, investment failures by outside entrepreneurs and the almost complete lack of residents' knowledge and information about the strength and direction of geomorphological changes have generated psychological insecurity and fatalism among the villagers. This was frequently perceived during our interviews. The repetition of dysfunctional reactions to erosion patterns, such as the abandonment of old fish traps which in turn enforce undesirable local erosion and sedimentation patterns is another case in point [10]. Erosion, and the particular way in which the local population reacts to it in its presently uninformed situation, plays the central role in a vicious circle, where income diversity reduction is caused by erosion, this diminishes socio-economic stability and diversity and increases poverty which in turn render beach populations' livelihoods even more vulnerable to the dynamic nature of beach morphology. These findings are supported by the study of Correa [54], who shows, that relocation into the interior avoids repetitive alongshore directed relocations which would only prolong erosion and property risks and lead to recurring economic losses.

Social spatial differentiation in the community of Ajuruteua reflects the options of different economic groups to react to morphological dynamics. Rising population numbers increase pressure on coastal resources and generate spatial differentiations and micro-migrations within the locality. As the coastline changes in locally unpredictable ways, the community of Ajuruteua continues to suffer from socio-economic instability and increased socio-economic risks such as loss of infrastructure and means of production and health deterioration. A better-informed local population, able to comprehend geomorphological dynamics would be able to generate positive co-evolutionary potential.

5.3. Stability by remedial actions?

As would be required from ICM planning tailored for the region the principal system elements which govern the interactions between humans and their environment in the research area were identified. In summary these are: the size of the management units, erosion, effects of the erection of large fish traps as obstacles to the natural sediment cycle, damage to dune vegetation, removal of mangroves, loss of housing, micro-migration, fatalism and impoverishment of the poorer sections of the local population. As demonstrated by the numerous signs of physical and social degradation described above, their combined action has clearly weakened systemic resilience.

One additional and important factor relevant to ICM planning is the low degree of awareness of residents of their own key role in the initiation of erosion disasters in their village and its surroundings. The lack of local information on these linkages is clearly exacerbating the current situation. Any future ICM approach should therefore include a strong information and education component. Through the medium of better knowledge, local stakeholders' understanding of erosion problems and their natural and man-made causes as well as local prediction capacities would improve. Better knowledge would enable local people to increase their adaptive capacities and strategies vis-à-vis the natural sources of instability so that the evolution of alternative options for action for the local residents may occur.

It is argued here that the identified interlinkages between geomorphological and socio-economic instability are not cast in stone but that, on the contrary, local empowerment with available research knowledge can lead to desirable co-evolutionary patterns by significantly contributing to an increase in socio-economic diversity and stability and its resilience towards erosion in beach areas.

6. Conclusions

By integrating socio-economic information for a coastal fishing village with information on coastal morphodynamics, changes and trends became detectable and could be examined from a spatial perspective. Several aspects of the natural system, most importantly erosion, exert a substantial influence on the anthropogenic subsystem and are affected by it. Our case study highlights that socio-economic structure has to be viewed as a co-evolving component of the coastal system. The socio-economic organisation and structure of a coastal community may thus play a similarly central role as an indicator for the state of a coastal system as the predominant hydrodynamic signatures.

Constrained options for the local population led to disparate coastal utilisation patterns by different social groups and to distinct residential distribution patterns in the three different village sections. This emphasizes the need for small-scale development approaches, which is also underlined by the rather small size of coastal management cells (1–3 km length), identified by the geomorphological analysis. These smallness of the management units is an additional indicator for the close relationship between human utilisation and coastal morphodynamics. Beyond this, remedial actions within an ICM approach should start with the dissemination of knowledge about the important role which local stakeholders play in their erosion-prone environment.

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References

[1] Thom BG. Coastal landforms and geomorphic processes. In: Snedacker S, Snedacker J, editors. The mangrove ecosystem: research methods. Unesco/SCOR Working Group 60 on Mangrove Ecology. Paris: UNSECO; 1984. p. 3–17.

[2] Cater RWG. Coastal environments. London: Academic Press, 1988. 617pp.

[3] Masselink G, Short AD. The effect of tidal range on beach morphodynamics and morphology: a conceptual beach model. Journal of Coastal Research 1993;9(3):785–800.

[4] Twilley RR. Properties of mangrove ecosystems related to the energy signature of coastal environments. In: Hall CAS, editor. Maximum power. The ideas and applications of H.T. Odum. Niwot: University Press of Colorado; 1995. p. 43–62.

[5] Short AD. Handbook of beach, shoreface morphodynamics. Chichester: Wiley; 1999. 392pp.

[6] Woodroffe C. Mangrove sediments and geomorphology. In: Robertson AI, Alongi DH, editors. Tropical mangrove ecosystems. Coastal and estuarine studies 41. Washington, DC: American Geophysical Union; 1992. p. 7–43.

[7] Hogarth PJ. The biology of mangroves. Oxford: Oxford University Press; 1999. 228pp.

[8] James RJ. From beaches to beach environments: linking the ecology, human-use and management of beaches in Australia. Ocean & Coastal Management 2000;43(6):495–514.

[9] Gupta A, Ahmad R. Geomorphology and the urban tropics: building an interface between research and usage. Geomorphology 1999;31(1–4):133–49.

[10] Krause G, Soares C. Analysis of beach morphodynamics on the Bragantinian mangrove peninsula (Pará, Northern Brazil) as prerequisite for coastal zone management recommendations. Geomorphology; in press.

[11] Nordstrom KF, Jackson NL, Bruno MS, Butts HA. Municipal initiatives for managing dunes in coastal residential areas: a case study of Avalon, New Jersey, USA. Geomorphology 2003;47:137–52.

[12] Mazda Y, Magi M, Nanao H, Kogo M, Miyagi T, Kanazawa N, Kobashi D. Coastal erosion due to long-term human impact on mangrove forests. Wetlands Ecology and Management 2002;10:1–9.

[13] Norgaard RB. Sociosystem and ecosystem coevolution in the Amazon. Journal of Environmental Economics and Management 1981;8:238–54.

[14] Norgaard RB. Development betrayed. The end of progress and a coevolutionary revisioning of the future. London: Routledge; 1995. 280pp.

[15] Henkel K. Agrarräumliche Entwicklungen im östlichen Pará (Amazonien), unter besonderer Berücksichtigung kleinbäuerlicher Landwirtschaft. In: Kohlhepp G, editor. Brasilien—Beiträge zur

regionalen Struktur—und Entwicklungsforschung. Tübinger Geographische Studien. Tübinger Beiträge zur Geographischen Lateinamerika-Forschung 1. 1987. p. 255–74.
[16] Maneschy MC. Ajuruteua. Uma comunidade pesqueria ameaçada. Belém: UFPA, 1995. 167pp.
[17] Berger U, Glaser M, Koch B, Krause G, Lara R, Saint-Paul U, Schories D, Wolff M. An integrated approach to mangrove dynamics and management. Journal of Coastal Conservation 1999;5: 125–34.
[18] Krause G, Schories D, Glaser M, Diele K. Spatial patterns of mangrove ecosystems: the bragantinian mangroves of North Brazil (Bragança, Pará). Ecotropica 2001;7:93–107.
[19] IBGE (Instituto Brasileiro de Geografia e Estatística). Sinopse Preliminar do Censo Demográfico 2000. Brasília. CD-Rom.
[20] Glaser M. Interrelations between mangrove ecosystem, local economy and social sustainability in Caeté Estuary, North Brazil Wetlands Ecology and Management. Special Issue: Amazonian Mangroves 2003;11(4):265–72.
[21] Glaser M, Grasso M. Fisheries of a mangrove estuary: dynamics and interrelationships between economy and ecosystem in Caeté Bay, North-Eastern Pará, Brazil. Boletim do Museu Paraense Emilio Goeldi Série Zoologia 1998;14(2):95–125.
[22] Aurada K. Modellbildung und Theorieentwicklung in der Physischen Geographie. Beiträge zur Regionalen Geographie 1996;42:76–9.
[23] Grimm V. To be, or to be essentially the same: the "self-identity of ecological units". TREE 1998;13(8):298–9.
[24] Hinga KR. Predicting the effects of habitat change on marine populations. Intercoast Network 1998;32:5–6.
[25] Jax K, Jones CG, Pickett STA. The self-identity of ecological units. Oikos 1998;82(2):253–64.
[26] Berkes F, Folke C. Linking social and ecological systems. Management practices and social mechanisms for building resilience. Cambridge: Cambridge University Press, 1998. 495pp.
[27] Brunsden D. A critical assessment of the sensitivity concept in geomorphology. Catena 2001;42: 99–123.
[28] Schaeffer-Novelli Y. Manguezal—Ecossitema entre a terra e o mar. Sao Paulo: Caribbean Ecological Research, 1995. 64pp.
[29] Kjerfve B, Lacerda L, Diop E, editors. Mangrove ecosystem studies in Latin America and Africa. Paris: UNESCO; 1997. 349pp.
[30] Rönnbäck P. The ecological basis for economic value of seafood production supported by mangrove ecosystems. Ecological Economics 1999;29:235–52.
[31] Lakshimi A, Rajagopalan R. Socio-economic implications of coastal zone degradation and their mitigation: a case study from coastal villages in India. Ocean & Coastal Management 2000;43(8–9): 749–62.
[32] Olsen SB, Lowry K, Tobey J. A manual for assessing progress in coastal management. The common methodology for learning. Coastal Management Report No. 2211. Narragansett: Coastal Resources Centre; 1999. 56pp.
[33] Boczar-Karakiewicz B, Jackson LA, Kohlhase S, Naguszewski A. Beach dynamics of barred nearshores: Gold Coast, South Pacific and Island Sylt, North Sea. In: Sterr H, Hofstede J, Plag HP, editors. Proceedings of the International Coastal Congress, Kiel. Interdisciplinary Discussion of Coastal Research and Coastal Management Issues and Problems. Frankfurt am Main: Peter Lang; 1992. p. 487–94.
[34] Dong P, Chen H. A probability method for predicting time-dependent long-term shoreline erosion. Coastal Engineering 1999;36:243–61.
[35] Cooper NJ, Leggett DJ, Lowe JP. Beach-profile measurement, theory and analysis: practical guidance and applied case studies. Water and Environmental Management: Journal of the Chartered Institution of Water and Environmental Management 2000;14:79–88.
[36] FitzGerald DM, Buynevich IV, Fenster MS, McKinlay PA. Sand dynamics at the mouth of a rock-bound, tide-dominated estuary. Sedimentary Geology 2000;131:25–49.
[37] Klein AHF, Menezes JT. Beach morphodynamics and profile sequence for a Headland Bay Coast. Journal of Coastal Research 2001;17(4):812–35.

[38] Dean RG. Beach profiles. In: Herbich JB, editor. Handbook of coastal and ocean engineering 2. 1st ed. Houston, London: Gulf Publishing Company; 1983. p. 715–33.
[39] Wright LD, Short AD. Morphodynamic variability of surf zones and beaches: a synthesis. Marine Geology 1983;56:93–118.
[40] Greenwood B, Davis RA. Hydrodynamics and sedimentation in wave-dominated coastal environments. Developments in sedimentology, vol. 39. Amsterdam: Elsevier; 1984.
[41] Short AD, Aagaard T. Single and multi-bar beach change models. Journal of Coastal Research 1993;15:141–57.
[42] Levoy F, Anthony EJ, Monfort O, Larsonneur C. The morphodynamics of megatidal beaches in Normandy, France. Marine Geology 2000;171:39–59.
[43] Hansom JD. Coastal sensitivity to environmental change: a view from the beach. Catena 2001;42:291–305.
[44] Emery KO. A simple method of measuring beach profiles. Limnology & Oceanography 1961;6:90–3.
[45] Krause G. The "Emery-Method" revisited—performance of an inexpensive method of measuring beach profiles and modifications. Journal of Coastal Research; in press.
[46] Fundaçao National da Saude Survey, unpublished data, Bragança. 2003.
[47] Barletta M, Barletta-Bergan A, Saint-Paul U. Description of the fisheries structure in the mangrove-dominated region of Bragança (State of Pará—North Brazil). Ecotropica 1998;4:41–54.
[48] Glaser M, Krause G. Integriertes Küstenmanagement im föderalen Brasilien: Institutionelle, sektorale und legale Strukturen und die Grenzen der partizipativen Planung. In: Glaeser B, editor. Küste, Ökologie und Mensch—haben sie eine Zukunft? Berlin: LIT-Verlag; in press.
[49] Castro E. Território, biodiversidade e Saberes de Populações Tradicionais. In: Castro E, Pinton F, editors. Faces do Trópico Úmido-Conceitos e Questoes sobre Desenvolvimento e Meio Ambiente. Belém: Editora CEJUP; 1997. p. 221–42.
[50] Furtado LG, Leitao W, Fiuza de Mello A, editors. Povos das Águas: Realidade e Perspectivas na Amazônia. Belém: Museu Paraense Emilio Goeldi; 1993. 292pp.
[51] Nduma I, Kristjanson P, McPeak J. Diversity in income-generating activities for sedentarized pastoral women in Northern Kenya. Human Organization 2001;60(4):319–25.
[52] Lipton M. Assessing village labour situations in developing countries. Study prepared for the International Labour Office, Oxford: Institute of Development Studies, 1978. 180pp.
[53] Krause G. Coastal morphology, mangrove ecosystem and society in North Brazil. Elements determining options, resilience. Ph.D. thesis, Stockholm: Stockholm University; 2002. 40pp.
[54] Correa ID, Gonzalez JL. Coastal erosion and village relocation: a colombian case study. Ocean & Coastal Management 2000;43(1):51–64.