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An integrated approach to mangrove dynamics and management

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Abstract. The main objective of the MADAM project (Mangrove Dynamics and Management) is to generate the scientific basis enabling the sustainable stewardship of the resources of the Caeté mangrove estuary in Northeast Brazil in the sense of integrated coastal (zone) management. To achieve this, it is necessary to acquire in-depth knowledge of natural processes as well as of the relevant institutional, cultural, economic, social and political dynamics. Causal linkages within the ecosystem, as well as between ecosystem, economy and society, are analysed and explained via dynamic and trophic modelling. Scenario construction is intended to forecast the effects of acute or chronic interference on utilized resources, and to answer wider, management-related questions (e.g. restoration of destroyed areas, utilization potential for aquaculture). This paper describes the project strategy as developed and modified in the context of research results from the initial 2-yr project phase. It is argued that a continuous discussion process is essential to assess the validity of the strategies formulated at the beginning of a medium-time project, particularly if the project is of interdisciplinary nature.

Keywords: Brazil; Caeté estuary; Coastal zone; Transdisciplinary research.

Introduction

The research region is the mangrove estuary of the Caeté river, 150 km south of the Amazon delta in northern Brazil. It forms part of the world's second largest continuous mangrove region, estimated to cover a total area of 1.38 million ha along a coastline of ca. 6800 km (Kjerve & Lacerda 1993).

The study area is the Caeté estuary which includes the mangrove-covered peninsula on the northwest side of the estuary (Fig. 1). The size of the study area is ca. 250 km^2, about half of which is covered by mangrove forest. The first socio-economic surveys in the villages of the region (Glaser unpubl.) showed that ca. 80 % of the households live from the diverse products of the mangrove estuary whereas ca. 68% derive income from the mangrove ecosystem. The economically most important mangrove product is the callaloo crab (*Ucides cordatus*). Fish, shrimps and other invertebrates as well as mangrove timber are also used, the latter predominantly to fire brickwork kilns.

Although the ecology of the Caeté ecosystem is considered to be relatively undisturbed by human activities, there are visible trends of expanding tourism, intensification of the fishery industry and of urban growth in the area.

Little research has been carried out in the region. Moreover, despite the fact that – judged by the sheer number of botanical, zoological and ecological studies – mangroves must be among the most intensely studied tropical ecosystems (Twilley 1996), there has been insufficient progress in the integration of the various studies which would allow for a better understanding of any mangrove system as a whole and of its key processes. As a result, the application of the research results obtained by other projects to a new study area is problematic. However, such an integration is clearly imperative for an ecosystem research approach which intends on the one hand to create the capacity to assess the implications of human resource use dynamics, or of changes in hydrographic, geomorphological or climatic conditions for the ecosystem, and on the other hand to explore the possible effects of natural or regulative changes on the relevant social and economic structures. It was also assumed that if recommendations for ecosystem management are to be elaborated, the socio-economic value of the ecosystem needs to be determined as a guide to decision-making. The possible scenarios for future mangrove use, as derived from various management approaches and variables such as population growth and employment trends, must be linked in such a way that the scope for activities and decision-making pertaining to the ecosystem becomes evident. To do this, it is necessary in the first place to achieve a minimum interdisciplinary consensus on the precise local meaning of key management goals, such as sustainability. In the identification of management problems and solutions, the involvement of system users and other key stakeholders is considered essential (cf. Özhan 1998).

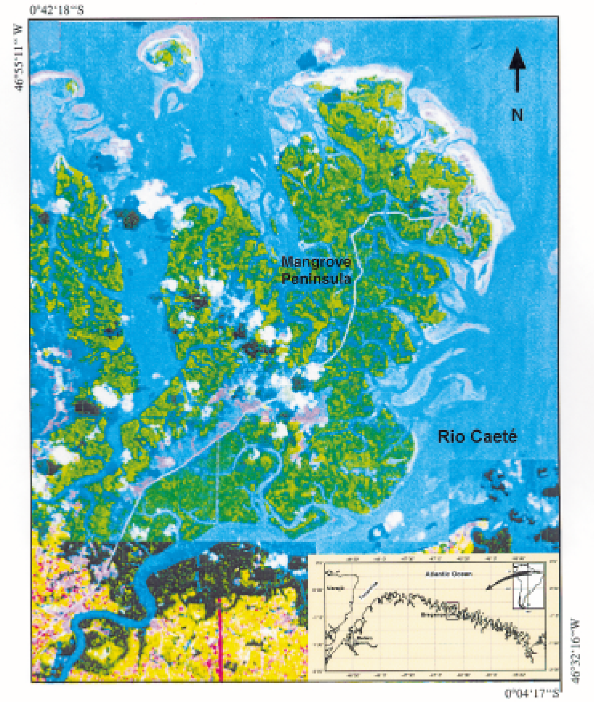

Fig. 1. Research area. The research area of the MADAM project covers a mangrove ecosystem of roughly 110 km^2 and is located south of the mouth of the Amazon, near the town of Braganca. The area is situated ca. 220 km east of the main capital Belém of the State of Pará, Brazil. Geographically it belongs to the region of the Amazon Oriental and has the typical climate of the inner tropics: annual mean temperature is 25.7 °C, annual rainfall is ca. 2550 mm. Thus, the requirements for mangrove growth are met. The satellite image Landsat TM 1988 displays the Peninsula, which is covered predominantly by mangroves – *Rhizophora mangle, Avicennia germinans* and *Laguncularia* spec. The pink-coloured areas in the lower inner part of the Peninsula are degraded mangroves, in the lower left corner are some of the adjacent villages (lighter pink), agriculture land (yellow) and secondary forest (light green). In the North of the Peninsula are two settlements (light pink) – the smaller one, to the right, is a traditional fishing village; the other one, located directly along the sandy, dune-ridged coastline is an expanding tourist resort. The main feature of the research area is, however, the estuary of the Caeté River. The tidal range within the mangrove area can reach 3.70 - 4.00 m and is highly influenced by strong sediment dynamics. Fluxes of energy, organic and inorganic material from and to the mangrove take place. The estuary is a very important local source of income for commercial and subsistence fisheries (e.g. crab fisheries; *Ucides cordatus).*

Research goals

The aims of the work carried out within the MADAM project are:

- to provide the scientific basis for predicting and explaining the behaviour of the Caeté mangrove estuary under changing environmental conditions and utilization scenarios;
- to assess and compare the socio-economic implications and feasibility of different possible, ecologically sustainable mangrove resource management approaches;

These goals may be achieved by the following steps:

- development and integration of research results on the natural and anthropogenic processes operating in relation to the mangrove system;
- development of models for describing the behaviour of the mangrove system under specific scenarios, in order to elaborate management recommendations for ecologically sustainable utilization of the mangrove and its resources;
- development of models to outline the links between (1) ecosystem resources and services and (2) economy and society in order to outline the scope for ecologically, socially and economically sustainable ecosystem management solutions.

In relation to the first goal, the results generated by the project's ecological and socio-economic studies are to be linked to and analysed in conjunction with results from other projects in order to describe and locate the study area within a wider context. Recognizable patterns include geomorphological classification according to Thom (1984) and the sub-classification into ecological function types proposed by Lugo & Snedaker (1974). Beyond this the qualitative classification of the research area on the basis of visible ecological features must be supplemented by quantifiable parameters. In this context, measurements of e.g. primary production, exchange of organic material and nutrient cycling have been done within the MADAM project. Furthermore, *i.a.* systemic indices of complexity, the number of trophic levels, ecological efficiency, the ratio primary production:system biomass – as derived from the trophic modelling – will be used to characterize the structure and the degree of development of the system (Baird & Ulanowicz 1993; Ulanowicz & Mann 1981; Ulanowicz 1986). The Caeté estuary will also be compared with other aquatic coastal systems in respect to their resistance to disturbance (see Rutledge et al. 1976). Regarding the socio-economic aspects the research area shows a familiar pattern of showing the most direct and comprehensive interdependence between natural resource use and economic survival for the poorest rural inhabitants. This serves to underline the political relevance of the intended integration of social sustainability criteria into scenario modelling (see Adger 1997).

Related to the second research goal, the MADAM project focuses on the development of different dynamic models describing the main processes driving the ecosystem. These processes are, for example, the population dynamic of mangrove trees and of the crab *Ucides cordatus* or the extraction of the crabs by the local people. Any management of the main 'drivers' of the ecosystem will predominantly occur via the regulation of human resource use patterns with implications for social and economic sustainability. There is commonly a range of possible regulative options which attempt to achieve an identified resource use objective.

The third research goal aims at the development of integrated ecological and socio-economic risk assessment. This is necessary because management recommendations must give consideration to both nature conservation and the interests of those using the system. Therefore, a combination of biological, social and economic criteria when defining maximum sustainable resource yields of economically or socially crucial resources (mangrove trees, crustaceans, fish, etc.) needs to be found (Fig. 2). The socially and economically most sustainable solutions among the regulative options capable of achieving the same or similar ecological results must then be identified.

Research approach

The research goals are achieved with the following approaches (Fig. 3):

Description of matter fluxes between the Caeté estuary ecosystem and adjacent systems

The analysis of matter fluxes is essential; the export of nutrients – organic or inorganic – can play a crucial role for the productivity of the adjacent sea. Consequently, information is needed about the nutrient balance of the estuary which can be changed by anthropogenic impacts.

Identification, description and quantification of internal ecosystem processes and matter fluxes

In order to describe the system, it is first necessary to identify the most important groups of organisms (abundance and biomass) within the annual cycle. By calculating the rates of consumption and production, as well as describing the trophic relationships within the system, it is possible to work out an initial balance of the biomass fluxes within the overall system. Flows out of the natural system due to use by humans (products of the mangrove forest and the estuary) are also quantified, thus producing a link between ecological and socio-economic research.

Fig. 2. Subsistence fishery. Trapping barriers (curral) are impressive regional fishing devices. They are constructed close to the shore at places along the River Caeté and its estuary where they are less exposed to wind and the water currents are weak. Within the bay strong tidal currents cause large areas of erosion and shifting sandbank depositions (croa), which are suitable grounds for trapping barrier constructions.

Identification of absolute and relative importance of the mangrove ecosystem and its resources for economy and society and of consequent rationalities of user populations

One important aspect in the assessment of the importance of the mangrove ecosystem is the attribution of a monetary value to the ecosystem products and services useful to humankind. However, any natural resource is of different absolute and relative importance to the

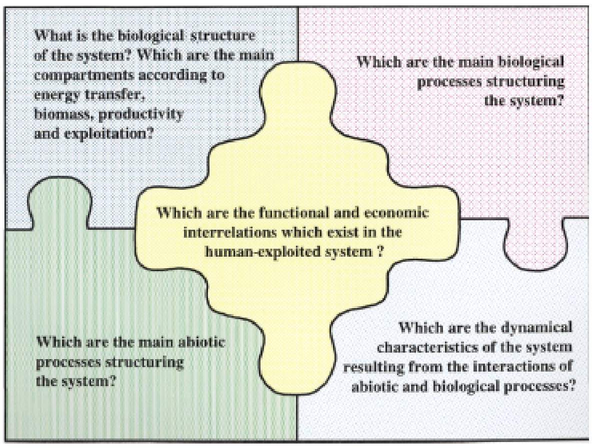

Fig. 3. Interdisciplinarity. Simplified picture of the interlinked questions formulated by the several sciences involved in the MADAM project. The integration of the usually distinguished approaches within one project illustrates the necessity of a combined system analysis to achieve the main goal of the project: understanding the mangrove dynamics and development of sustainable management strategies.

various sections of society so that the implications of, for example, non-availability will be different for different social groups. These different relevant social groups will need to be distinguished, and mangrove resource use will have to be located in its absolute and relative importance in the context of the totality of the socio-economic (survival) strategies of each group. The identification of priorities for the different users and other stakeholder groups and rationalities in relation to mangrove resource utilization constitutes an essential set of information for the development of utilization and management scenarios.

Integration of process studies using different and complementary modelling approaches

Beyond the use of one-species models for calculating the maximum long-term yield of particular key resources, it is planned to use additional models to describe the complex relationships between the major compartments of the ecosystem. Dynamic modelling of the mangrove forest in particular is of key importance. It is essential in this context to elucidate, through close collaboration between the various research disciplines, the specific factors that shape the dynamics of the mangrove forest in the study area. It is also important to develop methods to combine models and data sets from socio-economic rationalities and dynamics and natural processes.

Role of the various disciplines within the approach

Geography

The conceptual approach adopted by MADAM is that of Integrated Coastal Zone Management – in this Special Feature usually indicated as Integrated Coastal Management – an approach that must be supported methodologically in a variety of ways through field studies, evaluations of aerial photographs and satellite images and by setting up a Geographical Information System. Analysis of the following issues is of crucial importance in this context (Fig. 4):

• How can the data obtained from ongoing and future studies in all the participating research disciplines be integrated and holistically presented?

By developing a GIS based on the project's standardized data base system, it is possible to visualize the system components in terms of spatial and temporal parameters. The overview thus acquired, for example on questions concerning the variability of certain abiotic factors (salinity, pH, precipitation), the development of selected biotic components (e.g. distribution patterns of certain crab species) or the characteristic features of specific socio-economic parameters (e.g. settlement patterns or the spatial aspects of certain types of utilization), enables certain problems to be identified more quickly and to that extent is a major help in finding solutions. For example, by integrating knowledge about habitat preferences it will be possible to forecast the distribution densities of crab larvae and to identify the areas which are of most interest to people depending on crab extraction. Therefore, it will be possible to draw attention to potential land-use conflicts.

Biogeochemistry

In the first phase of the MADAM project, only the inputs and outputs of dissolved inorganic nutrients and dissolved and particulate organic carbon and nitrogen were quantified, with special reference to seasonal variability. The data collected throughout the year provide the basis for the production-biological studies. Additionally, physico-chemical, hydrological and meteorological parameters are recorded to answer the following questions:

• What are the principal sources of inorganic and organic nutrients in the mangrove ecosystem?

Inorganic and organic nutrients are absolutely essential for the survival of autotrophic (plants) and heterotrophic organisms (e.g. bacteria). If an ecosystem has a temporary or permanent shortage of nutrients, the biotic communities must develop adaptation strategies that will ultimately affect their structure.

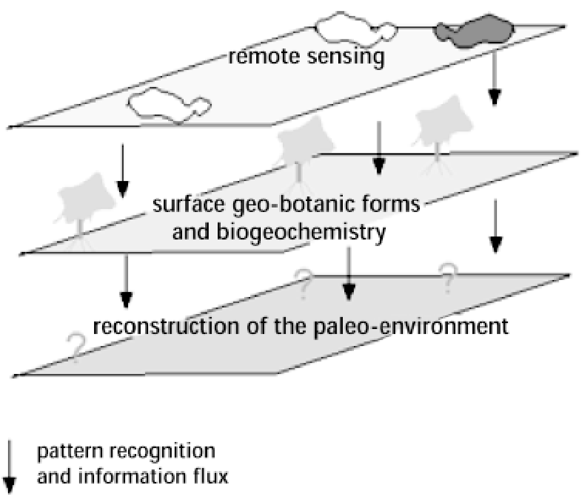

Fig. 4. Synoptic analysis concept. Project structure for the synoptic analysis of some core aspects of the mangrove ecosystem. Main goals are the recognition of geobotanical patterns, its interactions with the system biogeochemistry and the reconstruction of the paleo-environment. Each layer represents the recognition of large-scale patterns at the different structural levels with different methodologies. The arrows indicate the sequential priority and the flux direction of this information.

• Are these sources significantly affected by meteorological and/or hydrological factors?
An answer to this question is needed in order to identify the relevant driving forces. Major impacts on nutrient dynamics may arise from rainfall or tide-dependent flooding and other transport phenomena, as well as the chemical composition of the rainwater or the desiccation of sediments.

• Does the estuary function as a source or a sink for inorganic and/or organic material flowing into and out of the mangrove?

The estuary can function as a source of some inorganic nutrients and as a sink for others. It acts as a link between mangrove-covered land and the sea, and is therefore dependent on the nutrient concentrations of both ecosystems and on anthropogenic loads. If the latter are large, this will operate as a disturbance of the system, while a high discharge of nutrients – inorganic or organic – can play a crucial role in marine productivity.

Ecology

Ecological investigations focus on the following questions:

• Which habitat types can be distinguished within the system, and which communities are characteristic of these types?

The inventory of 'typical habitats' is followed by macro-scale structuring of the overall system as the basis for subsequent risk exposure analysis of the ecosystem. The latter analysis involves an assessment of the particular impacts that the loss or gain of sub-areas with certain qualitative features (e.g. species composition, resource productivity, recruitment potential for key species) will have on the overall system.

• Which are the most important interactions and the principal energy and material fluxes within the communities and the overall system?

In cooperation with the Biogeochemistry Working Group, attention is focused on the degree to which the biogeochemical cycles are influenced or disturbed by anthropogenic factors and whether (or how) this anthropogenic influence affects the nutrient supply and the productivity of the system and its utilized resources.

• Which spatio-temporal patterns are characteristic of the system and by which factors are they determined?

Spatial and temporal patterns observable in nature – e.g. periodic changes in the age structure of certain populations, or the spatial distribution of population densities due to organisms preferring certain habitats – are often shaped by features (biotic and/or abiotic) emerging from the system itself. The identification of such patterns and their interrelations in the Caeté mangrove estuary is particularly difficult, because mangrove areas are colonized by numerous species that straddle the transition between aquatic and terrestrial habitats, and species whose exact life cycles are still largely unknown. Conducting appropriate studies requires new methodological approaches, the development of which is one important aim of the project.

Socio-economics

The socio-economic research tasks in the study region focus, in the first place, on the identification, explanation and economic valuation of the patterns of human utilization of the mangrove ecosystem.

The following questions are raised in this context:

• What are the products, human use patterns and user groups associated with the mangrove ecosystem of the Caeté estuary?

The identification of ecosystem products and the assessment of the types and numbers of users for the immediate research area has been concluded. Currently ongoing is the quantification of utilization rates for the identified main products and user groups of the mangrove ecosystem. To develop credible scenarios of future utilization, the analysis of population, employment and income as well as supply and demand dynamics for the relevant system products is required. Utilization rates are important, not only for the economic valuation of the ecosystem and for the assessment of the socio-economic importance of mangrove products, but also as constituting parts of the trophic modelling work and of the analysis of fluxes of matter in the economy-ecology systemic complex. A further complement between research disciplines arises where the data on biological production rates of main ecosystem resources are required for the estimation of the resource potentials available for human utilization.

• What is the economic value of the Caeté estuary mangroves for the local residents, the user populations and the economy as a whole?

Economic valuation of the mangrove ecosystem is designed as a support to political decision-makers. The valuation data are derived from the quantification of mangrove product utilization rates, and also obtained via the simulation of markets for mangrove products or services for which no actual markets exist. The data for this exercise have been collected so that economic valuation of the system is now possible.

At the micro-level somewhat different questions arise in relation to mangrove use:

• Which are the social, political, institutional and economic driving forces of mangrove utilization for the rural producer households?

Rural households are the main users of mangrove ecosystems in North Brazil (Glaser unpubl. 1997, 1998). Therefore the MADAM socio-economic research will now focus on the links between ecological, economic and socio-political systemic processes and their respective logical underpinnings at the level of the rural producer household. The point of departure here is the categorization of different household types according to their specific production and income structures. The major objective is the contextualization and thus better comprehension of the resource utilization rationales specific to each mangrove producer household type.

• Which are the actual and possible regulative approaches and management solutions for the mangrove resources of the Caeté estuary?

The starting point for the development of appropriate legislation is an in-depth knowledge of existing regulatory frameworks. Since implementation failures rather than absence of legislation are often at the core of resource management problems, the distinction between failure to legislate and failure to implement needs to be clearly drawn. In view of the limited financial scope of the modern state, a law which is not/cannot be implemented needs to be considered inappropriate. It follows that any evaluation of existing regulative approaches needs to compare the actually achieved reality with that desired by the regulator. Ecologically, economically and socio-politically appropriate regulation recommendations for sustainable resource management need to be operationalized via legislative measures. Subsequently, both the appropriateness of such measures and actual implementation require long-term monitoring in order to allow for the improvement of management approaches.

The involvement of user and other stakeholder groups in the planning, implementation and monitoring processes is essential, not only because it bears the potential for eventual cost savings in the implementation process, but also, and more importantly, because it maintains or opens up spheres of influence for groups whose agreement to the selected management approaches is essential for their success. A major question in this context is:

• What is the scope for the involvement of user groups in the development and implementation of management approaches for important mangrove resources?

Because of factors such as increasing demographic pressures and growing consumer demand, the potentials and limitations of 'common property' or 'common pool' management of hitherto freely accessible, 'open access' resources have been a focus of research attention over the last few decades (see for example Feeny et al. 1990). The *Ucides cordatus* mangrove crab (Fig. 5) is a recent example of the, by now, familiar dynamics of imminent resource depletion in this context. Arising from the first phase of the research programme, MADAM has developed a more integrated interdisciplinary approach to establish the social, institutional, political and economic context of possible participatory, common property management approaches for the coastal environment in North Brazil. Simultaneously, it has, by biological monitoring, examined the ecological outcomes of participatory management pilot experiments. Cooperation with technical assistance bodies, in particular local NGOs, is at present in its initial phase but is considered essential for the success of this approach since the objectives of group management surpass those of pure research projects. On the other hand, the management-orientation of the MADAM project makes an assessment of the potential of participatory and co-management approaches an essential component of the research programme. Due to its very nature, such participatory potential for sustainable resource management can only be explored via transdisciplinary cooperation. By involving 'actors' from outside the research world (e.g. resource users, administrators), transdisciplinary investigations go beyond the boundaries of interdisciplinary research.

A further important question arising in the context of inter- and transdisciplinary research is:

• Is the current use of the Caeté mangrove estuary sustainable; are there alternative ecologically, socially and economically sustainable utilization scenarios?

Fig. 5. The landcrab *Ucides cordatus* is the economically most important resource of the mangrove system. Annual landings are ca. 4000 metric tons. Biomass is ca. 100 g/m^2. As landcrabs are strictly herbivorous, a strong influence on vegetation structure can be expected because of a high feeding rate – ca. 600 g litter/m^2/yr.

Sustainability can only be assessed in conjunction with all involved research disciplines and ecosystem stakeholders. The definition of sustainability is likely to be both multifactorial and regionally and locally specific. It can contain possible compromises with reference to target conflicts. It is important to have a widely agreed sustainability definition as a point of reference for successful management.

It is clearly essential in the socio-economic field to evaluate the present and probable future intensities of system use. Regarding potential utilization scenarios for the Caeté mangrove estuary, for instance by greatly intensified tourism, statutory controls on forestry, creating ponds for shrimp farming, etc., the crucial issue is to anticipate the consequences in areas such as land-use, exploitation of resources or degradation of key habitats. Ecologically important areas in the region may then be recommended for protection. 'Actors' such as municipalities, village communities and decision-makers (e.g. environmental authorities and the local government) are target groups for discussion and information campaigns in such a case. Suitable media include information events, training programmes, brochures and videos. Since, particularly in poorer countries, it is usually the poorest of the poor who depend most on natural resource use for their economic or even mere survival, ecological regulations can carry in their wake a range of inequitable socio-economic consequences and possible necessary social and economic support measures. The inclusion of female crab processors in the estimation of the costs of legislation of *Ucides cordatus* production is a case in point in the MADAM research area (see also Vivian 1990). The options for alternative legislative measures with similar ecological but dissimilar socio-economic consequences therefore have to be explored and the possibilities of compensatory measures for groups particularly hit hard by ecologically justified resource use limitations must be considered.

Projects which aim at management concepts for sustainable resource management also need to take account of the needs of resource users and decision-makers. This is only possible in the context of a comprehensive public relation and communication programme. More often than not, this is considered to be beyond the responsibilities of a research project and left to administrative or technical personnel. However, without the support of the affected populations and the important decision-makers, the development of realistic and applicable management solutions is likely to remain theoretical. Moreover, the advancement of methods of public discussion with system stakeholders is a task for the social sciences for which important natural science contributions are required.

Modelling

Our strategy for achieving the research goals involves a combination of different modelling approaches aimed at combining the respective benefits of global system analyses (trophic model of biomass flows), detailed process studies ('forest model' simulation package) and a risk assessment, combining both ecological and socio-economic aspects. In this way, it is possible to respond to the constant advances in scientific knowledge of all the participant research disciplines. On the one hand, the empirical work can be well-focused on key processes and sensitive parameters as they become apparent, while on the other hand it is also possible to develop and refine the overall concept. This dynamic interplay between theory and empirical study forms the basis for efficient, transdisciplinary work over the relatively long project duration of 10 yr. The following questions shall be explored in each respective case:

1. *How is the system structured biotically and which are the most important compartments with regard to energy transfer, biomass, productivity and utilization*?

Based on trophic modelling techniques, the elements (populations) are primarily grouped according to organism size, inter-generational period and food spectrum into functional compartments, this reduces the variety of organisms to a manageable number of system elements. From the degree of linkage between these compartments, and from the biomass flows between them, indices can be computed for the complexity, number of trophic levels, ecological efficiency, primary production of the system in relation to the system biomass and system respiration, as well as indices for characterizing the structure and the level of organization exhibited by the system (Baird & Ulanowicz 1993; Ulanowicz & Mann 1981; Ulanowicz 1986). This will enable a quantitative comparison of the ecosystem under study with others and also allow a grouping of ecosystems according to degree of maturity and resilience to disturbances (Christensen & Pauly 1993; Rutledge et al. 1976; Wolff 1994; Wolff et al. 1996).

Since trophic modelling proceeds from an equilibrium, only the structure of the system can be analysed; not the forces that shape the behaviour of populations when framework conditions change. Therefore, a further dynamic modelling approach based on the following questions has been developed.

2. *What are the biological and abiotic processes that structure the system, and the emergent characteristics of the system that result from their interaction*?

Since the forest stand of the Caeté mangrove estuary represents its primary component, development of a 'mangrove forest' simulation pack is ongoing as a tool for studying the population dynamics of the various tree species in the area. A rule-based approach enabling the inclusion of both quantitative data and qualitative knowledge will be used to construct this model. A substantial part of the data required is being collected as part of the 'forest types' sub-project that was jointly planned by scientists from the fields of socio-economics, biogeochemistry, ecology and theoretical ecology.

Additional models are planned, as was the case with the forest stand, for examining the temporal and spatial dynamics of the other main components of the system (especially crabs).

3. *Which functional economic interrelations exist within that part of the system used for economic purposes by humans*?

Before functional interrelations can be identified it is essential, from the economic science perspective, to value the existing resources, the present intensity of use and to forecast future trends for these two aspects. As suitable aids in this respect, point-based dynamic models will be developed which concentrate on the valuation of commercially used system resources – such as fisheries, crab fishing and timber use – including the associated marketing structures. Not only biological factors (natural production potential), but also economic factors must be taken into account in the calculation of maximum resource yields – in the sense of maximum sustainable yield (MSY) and maximum economic yield (MEY). Moreover, attention needs to be paid to questions of social equity, social resilience and institutional sustainability (see Pontecorvo 1986; Adger 1997).

Finally, it is of central importance for the overall success of the MADAM project that the following question is satisfactorily answered.

4. *What is the present intensity of ecosystem utilization, and which forecasts can be made with regard to the long-term development of the ecological/economic system*?

Socio-economic models attempt to identify as precisely as possible the anthropogenic links with the ecosystem, i.e. to specify the role of nature as a resource to people, and the relationship between society and nature, but tend to neglect the biological and abiotic interactions. In contrast, many ecological models describe the natural processes in great detail, but tend to leave out the human factor either entirely, or merely include anthropogenic 'interference' (e.g. in the form of 'harvesting rates') so that the human role is reduced to that of 'disturbance factor' or 'predator'.

Our ultimate goal is to overcome the respective shortcomings of natural science and social science models via the development of a spatially and temporally oriented economic/ecological simulation package which allows optimization of the needs for nature conservation and the demands for economic use of the resources of the ecosystem. This will be attempted via socio-economic/ecological risk assessment methods (Berger & M. Glaser in press).

Discussion

The interdisciplinary planning of the MADAM research concept generated a considerable initial need for discussion of the divergent perspectives from the participating research disciplines. A main theme here was the definition of the system to be studied, and thus the selection of the most appropriate scale. The idea of a shared definition was eventually abandoned in favour of granting each scientific discipline a specific time scale according to their respective research issues. Despite this consensus, individual scientists were not free to decide whether they wanted to work on a point- or area basis, with seasonal or annual cycles, but were in a position to derive their necessary operational scales from the overall project objectives.

The geochemical studies of matter fluxes for example concentrated on two points within the investigated mangrove area (Bragança peninsula) selected by geomorphological criteria and one transect at the mouth of the Caeté estuary. The biological studies of zoo- and phytoplankton concentrated on the same study sites as the geochemical analyses, whereas the botanical investigations of the mangrove forest focused particularly on a 4 km^2 area in the middle of the peninsula (but bordering one of the biogeochemical investigation points). In contrast to the above, the socio-economic investigations included survey data about all settlements utilizing the mangrove area under study. To combine all these results the point or transect-related measurement programmes are being expanded in such a way that explanations can be given for the processes in the entire research area (e.g. determination of the exchange and retention times of the water masses between the narrow mangrove channels, the estuary and the open sea). When planning measuring programmes, efforts are made to ensure that the research work performed by the various disciplines forms a united and consistent entity, such that the spatial and temporal scales of investigations are harmonized, or can be extrapolated against each other. The approach employed uses, *i.a.*, pattern recognition methods that allow botanical data, in particular, to be correlated with physico-chemical parameters of mangrove soils.

Initial results from the sedimentation studies (G. Krause et al. in prep.) indicate that mangrove trees perish and re-colonize much more quickly in the research area as a result of changed sedimentation conditions in selected sections of the coast and in the forest than was originally assumed for 'normal' population dynamics (Fig. 6).

The implication for the project is that the stability of the river courses and coastline should be made a priority focus in subsequent project work. Therefore, new study strategies were defined for the second project phase, in collaboration with geographers, biologists, geomorphologists and soil scientists. These studies include investigations of sediment transport processes in order to clarify questions concerning the origin of sediments in the dying mangrove areas and the dynamics of sediment loads in the inner part of the estuary (large sandbanks, e.g. in the Furo do Chato estuary), investigation of the dying process of mangrove trees (causes, speed, succession, spatial expansion) due to increased sand deposition and investigations of the resettlement of mangrove trees (succession, speed, differences to forests fringes in the estuary, spatial expansion) on newly created shorelines.

Contrary to all expectations, no recruitment of young *Ucides cordatus* crabs could be ascertained in the research area in the year 1997. Whether this is a manifestation within the normal range of system variability (i.e. a bad recruitment year), or expresses a long-term disturbance of the system, can only be clarified over a test span of several years. Analogously, the growth of fallow lands or islands of deadwood in forest areas, for example, could be an alarming indication of disturbance, or a natural stage within the vegetation dynamics of the research area, as is currently being discussed in the mosaic cycle theory in forests dynamics (Mueller-Dombois 1987; Remmert 1991; Akashi & Mueller-Dombois 1995).

The above examples have shown how important it is for ongoing and planned research work to recognize spatial and temporal patterns. Depending on the scale being studied and the particular research issue, it is necessary to find techniques and methods for compiling the mass of data from the various components of the MADAM sub-projects so that the data can be analysed and interpreted in relation to the respective questions. The main instrument in this context is the project data base currently under construction, together with the geographical information system being produced for the research area – the Mangrove Information System, MAIS. Analysis of aerial pictures (taken from satellites and aircraft) will serve to establish a suitable cartographic basis and will also help to detect and interpret structures that are characteristic of the system. The MAIS data base must be designed and utilized in such way that all the data produced during the project can be stored, searched and reproduced, without redundancy and in appropriate documentary form, such that the demands levelled at the system by scientists in all sub-disciplines are met. A further goal is to make all MAIS data accessible through the database (named PANGAEA) at the Alfred Wegener Institute for Polar and Marine Research (AWI), so that the results of the project are available to a larger set of users. One offshoot, for example, is that the data can be accessed from Brazil and Germany through the World Wide Web; redundancy and update anomalies are avoided by ensuring that data input is managed centrally by one person.

Fig. 6. Sedimentation processes. Initial results from the sedimentation studies indicate that mangrove trees perish and recolonise much more quickly in the research area as a result of changed sedimentation conditions in selected sections of the coast than was originally assumed.

Besides the scientific findings, one of the most relevant results of the first project phase was the establishment of a solid discussion base and the creation of a common language among the participants (scientists of the different disciplines, stakeholders and decision-makers of the region). This provided the tools for a discussion process where the validity of the strategies developed is continuously checked. We believe that only in this way can the general research goals be reached without losing contact with global reality and local needs.

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