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Assessing catchment-coast interactions for the Elbe by linking scenarios, indicators and modelling

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Abstract

While eutrophication creates impacts on coastal ecosystems and can result in negative impacts on coastal eco-system services, its source is often located far away from the coast, related to nutrient emissions from river catchments. Within the EU funded EUROCAT project a chain of tools and models were applied to assess these catchment-coast interactions. The Elbe catchment-coast system is one of several case studies within EURO-CAT. Aim of the project is to support Integrated River Basin Management (IRBM), as targeted in the Water Framework Directive (WFD), in order to mitigate possible externalities induced in the coastal zone by socio-economic development in the catchment. The DPSIR-approach of the European Environment Agency was se-lected as the analytical tool to handle this complex man-ecosystem interactions. Scenarios represent possible futures in which environmental risk perception, societal interpretation of environmental risk and (coastal) vul-nerability will influence political targets, such as the WFD implementation. Some society drivers and related policies are qualitatively assessed under each scenario and the resulting ecological impact on ecosystem integ-rity is quantified by applying the North Sea ecosystem model ERSEM. The presentation will outline the as-sessment framework focussing on the link between scenarios, DPSIR-indicators and modelling of impacts for coastal waters from the Elbe plume. Future scenarios and related modelling results describing the ecological status of the German North Sea under different scenarios will be presented.

1 Introduction

The coastal zone is under heavy pressure from land-based activities located in the catchment of rivers. Traditionally, both scientific research and the governance framework have treated catchments and coasts as separate entities. However, it is increasingly recognised that they should in fact be treated as an integrated whole, encompassing both environmental and socioeconomic and political systems.

The EUROCAT project was established with an integrated perspective and analytical framework in mind. Across seven regional case studies, local teams of natural and social scientists used a common interdisciplinary strategy to:

- Identify the impacts on the coast
- Interface biophysical catchment and coastal models with socio-economic models
- Develop regional environmental change scenarios (2001-2020)
- Link scenarios with the modelling toolbox to evaluate plausible futures
- Evaluate research outcomes with regional boards consisting of stakeholders and policy makers.

Aim of EUROCAT is to promote and assist Integrated River Basin Management (IRBM), as targeted in the Water Framework Directive 2000/60/EC (WFD), in order to prevent and mitigate possible externalities induced in the coastal zone by socio-economic development in the catchment. Implementation of the WFD can be expected to form a major issue in future debates on local as well as regional level which makes the EUROCAT approach relevant for future discussions concerning sustainable regional development.

In EUROCAT initially five case studies were performed, focussing on the following river catchments and coastal areas:

1. Rhine-Elbe catchment and North Sea (RebCAT);
2. Humber catchment and Humber estuary (HumCAT);
3. Vistula catchment and Bay of Gdansk (VisCAT);
4. Po catchment and North Adriatic Sea (PoCAT);
5. Axios catchment and Bay of Thessaloniki (AxCAT);

In 2002/2003 two additional case studies were added:

6. Idrija catchment and North Adriatic Sea (IdriCAT);
7. Provadijska catchment and Black Sea (ProvaCAT);

The seven systems cover all coastal types (with the exception of fjords) in Europe and different socio-economic settings. The rivers Vistula, Rhine, Elbe Idrija and Axios are transboundary rivers. Eutrophication and in one case pollution (metals) were identified as major issues for the coastal zone.

Fig. 1: Case study areas in EUROCAT

The Elbe case study, on which this paper concentrates, is part of the RebCAT (Rhine and Elbe Catchment) case study. The focus of the investigation was on nutrient flows from the river to the coast and the impact on the coastal ecosystem, especially to eutrophication processes.

Complex types of impact assessments as they have been performed in RebCAT have to deal with the societal perceptions and interpretations of the ecosystem as well as with ecological dynamics. The paper refers to the link between society and ecosystems and the resulting implications for the scientific assessment framework as well as to the concept applied to measure ecosystem impacts for the German bight. The full RebCAT approach including the catchment modelling, which is based on the MONERIS model (Behrendt et al., 2000.) and the analysis of management responses will be published in Hofmann et al. (submitted).

2 General assessment framework

2.1 Society and ecosystems

The overall target of the Water Framework Directive, European Union (2000) is to achieve a good ecological status for coastal waters as well as for freshwater systems and aims thereby to reduce disturbing human impact as far as possible. According to this Directive, a "good ecological and chemical status" of waters is expected to be achieved after 15 years from the date (December 2000) of launching the Directive. The ecological status is defined by biological, physical and chemical characteristics of the ecosystem. While chemical status is defined by the use of quality standards in relation to priority substances found in the system, reference biological conditions are those that prevailed under pristine conditions so that human impacts are excluded. Core questions in this context are (Windhorst et al, 2004):

- Which amount of human impact on the ecosystem can be tolerated or to which degree the ecological services can be exploited whilst still maintaining a good ecological status of the ecosystem?
- Within which range of quality can ecosystems be classified to be good or - in other words - within which tolerable margin can the ecosystem structure and dynamics be allowed to deviate from the pristine conditions while at the same time considered as being classified as "good"?

To answer both questions is a prerequisite in order to define suitable management plans for the use of river catchments and coastal zones. On the other hand answering these questions is related to norms and values of the society. The societies and their decision makers have to be aware that ecosystem services encompass a broad range of issues that are partly contradicting with respect to the use of natural resources and are justified by a mix of ethical value settings (Barkmann 2000). Thus, the acceptable level of usage of ecosystem services is actually set by the power of different stakeholders to impose their will and societal regulations such as environmental laws. This means, that definitions and regulations of a "good ecological status" may vary with space and time, and even by cultures. For example, in the Adriatic Sea, fishermen would argue, that a higher level of eutrophication is beneficial for their haulage, while managers of tourism would prefer lower levels of eutrophication in order to minimise the effects on tourists.

Taking into account the uncertainties about the future needs of humanity, the future development of ecosystems in the light of global change and the current limited insight into the complexities of the ecological systems as well as of the socio-economic system, it is not feasible to identify exact values for each named ecosystem function which are critical in the sense, that risks for the ecosystem services may be avoided. On the other hand it seems possible and is in line with the Sustainable Development paradigm to follow the precautionary principle (Turner et. al 2001), and to develop management strategies which allow a maximum use of ecological services while keeping the ecosystem integrity at least at the present level, thereby reducing the risk of hazardous natural developments. Thus the target of the integrated approach is to inform the society about possible future trends and the connected risks, allowing the delineation an optimised balancing between "ecosystem use" and "ecosystem squeeze".

2.2 Assessment approach

The Driver-Pressure-State-Impact-Response-approach (DPSIR) is the analytical framework selected in EUROCAT (in accordance with international programs like LOICZ, GIWA, the EEA and others) to handle these complex humankind-ecosystem interactions. The definition of these terms had to be adapted to the needs of the EUROCAT project. To assist the assessment along the catchment-coast contimuum the partners in workpackage 2 (Indicators and Scenario Assessment) of EUROCAT decided that Drivers, Pressures and Responses need to be formulated for the river catchments as well as for the coastal areas. As the focus of EUROCAT is to view the coastal zone as receptor area of catchment activities, State and Impact indicators need to be developed only for the coastal area. On the other hand State and Impact have to be subdivided into ecological State/Impact and socio-economic State/Impact (Colijn et al. 2002).

In order to assess drivers, pressures, state, impact and responses as well as their cause-effect relationships, several tools had to be linked with each other (Figure 2). Scenarios have been used to identify and assess major drivers and their changes under different socio-economic conditions and different regulation frameworks. A full description of the approach including a comparison of the several EUROCAT case studies is given in Kannen et al (2004).

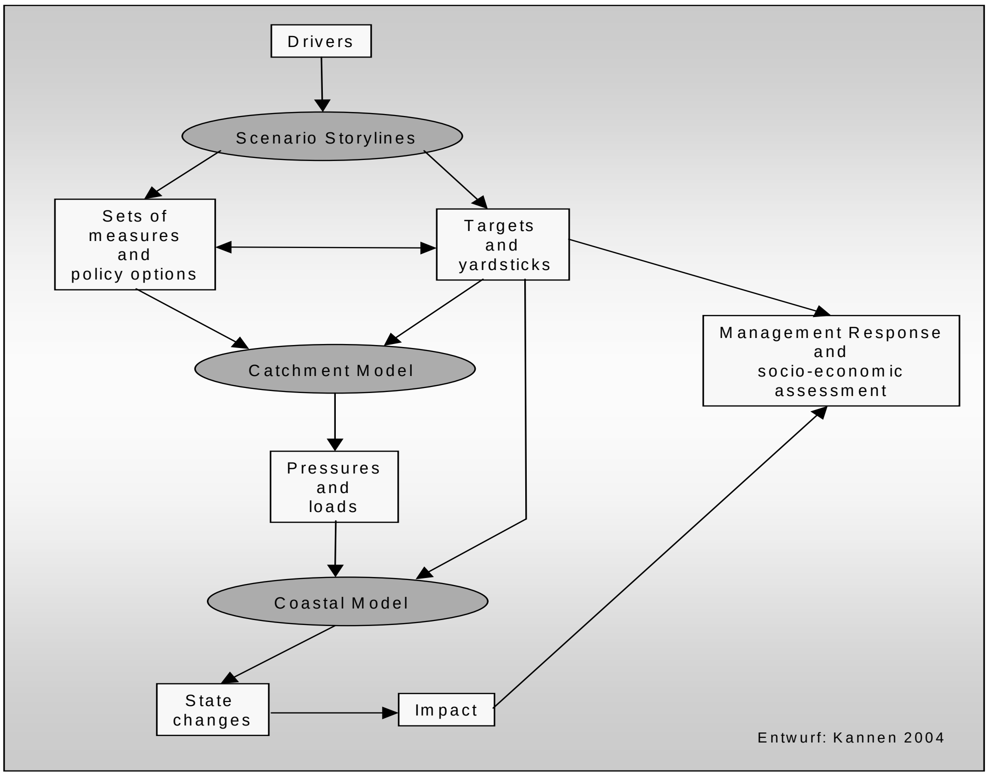

Fig. 2: Assessment chain along the catchment coast continuum in RebCAT (Kannen et al. 2004)

Scenarios represent a preview how different human activities could come into existence, thus causing an impact on the environment and potentially damaging the (coastal) ecological integrity. Furthermore scenarios as applied in RebCAT (Nunneri et al. 2002) represent plausible images of the future, in which environmental risk perception and therewith interpretation of environmental risk and (coastal) vulnerability will considerably influence political targets and their implementation.

The political issues, lifestyles and social values characterising different scenarios will exert pressures on the environment. Some society drivers such as urbanisation and food demand and their ecological impact on ecosystem integrity and function (e.g. heterogeneity) are qualitatively assessed under different scenario storylines. A relative evaluation of the different pressure intensities under different future conditions is the base for modelling changes in ecosystem state-parameters (e.g. species composition and ratio diatoms/flagellates for heterogeneity) and aggregated impact indicators corresponding to the demand of the WFD.

The scenarios for the Elbe case study area defined alternative sets of policy targets and related reduction targets. Catchment modelling and coastal modelling can use this scenario based reduction targets as input. The modelling exercise in the catchment was used to define measures that allow to reach these targets. The coastal modelling assessed the impact of the defined reduction targets on the coastal ecosystem according to the framework described in chapter 3.

3 Framework to measure ecosystem impacts

To identify the societal forces which drive the amount of ecosystem services used by human activities, the case study teams in EUROCAT developed scenarios addressing potential futures developments that are relevant for matter and energy fluxes in each specific catchment-coast continuum. For the Rhine-Elbe (REBCAT) case study six issues, namely Food Demand, Urbanisation, Energy Demand, Mobility and Transport, Industry and Housing and finally Nature conservation, which create pressures on ecosystems were selected and the direction and strength of changes under 3 societal scenarios assessed. For nutrient fluxes and coastal eutrophication as the investigated main issue in RebCAT, the riverine nutrient loads (nitrogen and phosphorus) are selected as forcing function or pressure indicator for the ecological change related to eutrophication processes in the coastal zone. The link between drivers and pressures is visualised in figure 3.

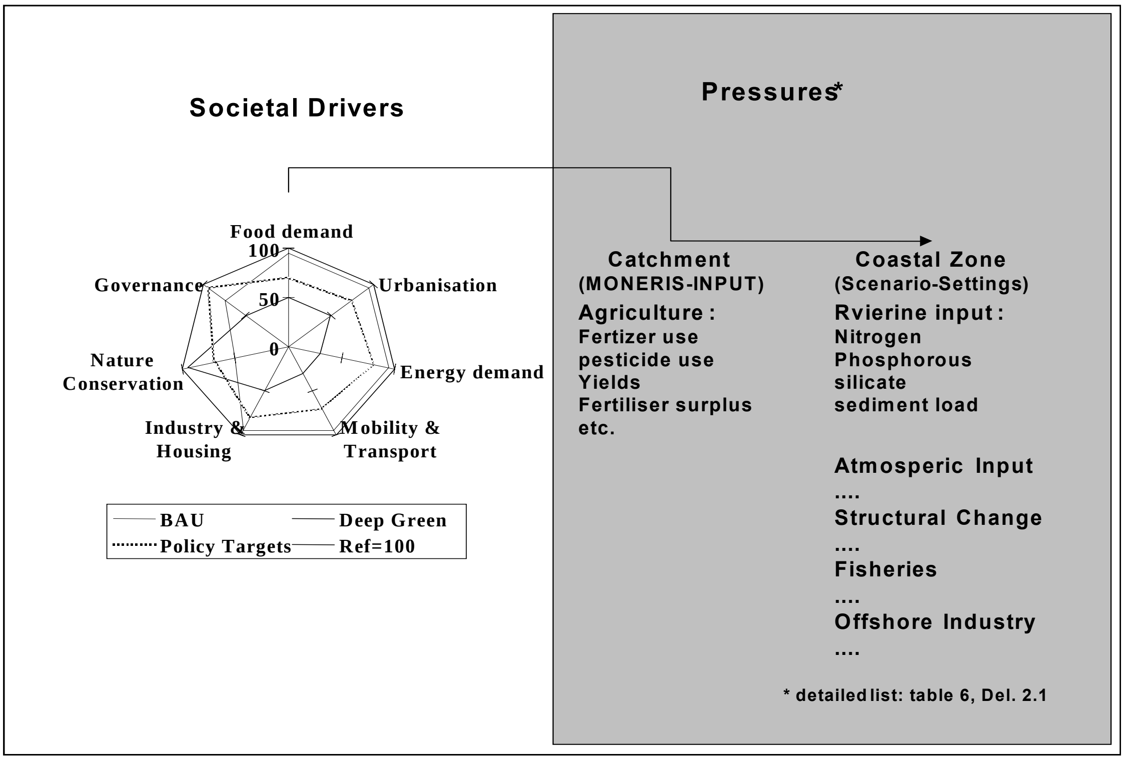

Fig. 3: Connecting Drivers and Pressures of the DPSIR-approach (Colijn et al. 2002)

As future numbers for parameters cannot be measured, the future environmental state needs to be assessed using modelling techniques. Therefore, the selection of measures to describe ecological impacts were dependent on available data and especially on available models for the river catchment and for the North Sea.

Based on ecosystem theory, a measure to describe ecological impacts in an aggregated form, is ecosystem integrity. Within the REBCAT study a specific interpretation of ecological integrity based on Barkmann & Windhorst (2000) has been used. This is described in detail in Windhorst et al. (2004). Ecological integrity therefore aims to describe the relationship between use of ecosystem services and ecological risks endangering the capacity of ecological systems to provide these ecosystem services. Operationally the ecological integrity can be defined as the guarantee that those processes at the basis of ecosystems self-organising capacity are protected and kept intact.

Based on ecosystem theory, exergy capture, cycling of elements, storage capacity, heterogeneity (diversity) and matter losses are important elements of ecosystem functions. With respect to eutrophication processes these indicators can be modelled taking state parameters as proxies (Windhorst et al.

forthcoming) and aggregating them into comparable amoeba, that describe the ecosystem integrity and the ecological impacts on the coastal system (Figure 4).

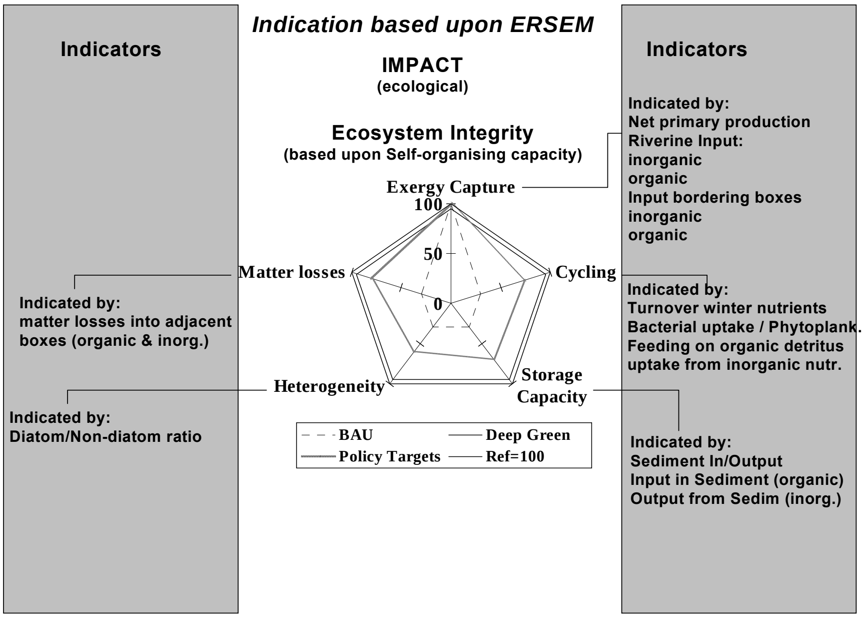

Fig. 4: Connecting ecosystem integrity with State and Impact of the DPSIR-approach (Colijn et al. 2002)

The selection of "Exergy Capture" as an indicator for ecosystem integrity stems from the "Non equilibrium principle as formulated by Kay (2000) and Jörgensen (2000). In coastal zones beneath solar radiation also energy flows coupled with organic and/or inorganic nutrient inputs from the atmosphere or from adjacent regions have to be taken into account. Another important process to enhance the self organising capacity of ecosystems is their tendency to (re)cycle limiting substances, especially nutrients. The availability of limiting nutrients and energy depends on the storage capacity, the exchange rate of the pools and the possibility to dampen or buffer temporarily external inputs. To which extent ecological systems are able to utilise this storage capacity depends on the heterogeneity and especially on the biotic diversity of the system. Finally matter losses reduce the capacity of primary and secondary production, which are essential functions of ecosystems.

This conceptual elements need to be linked with models in order to assess state parameters that allow the description of impact indicators within this framework. The approach outlined here to select indicators based on ecosystem theory is in accordance with the present discussion within international agreements like OSPAR or HELCOM concerning the application of the ecosystem approach in environmental policy making. It also fits into the definitions for Ecological Quality and Ecological Quality Objectives given by the North Sea Task Force (NSTF) which consists of experts from both OSPAR and the International Council for the Exploration of the Sea (ICES).

4 Scenarios

The scenarios for the Elbe are based on an approach that combines qualitative narratives with quantification of reduction targets. Qualitative storylines are used to achieve internal consistency and make scenarios more vivid, while quantification of key-variables are essential for providing data to the model simulations for the catchment emissions and for the ecological effects in the coastal zone.

The scenarios are described in Nunneri et al (2002). Their main difference are the social values and the lifestyle that develops within different worlds, driven by the rules "Global Markets" (priorities on economic growth and individual consumption), a "Strong EU" (strong policy management by regulations) or "Green Regions" (with strong emphasis on local economies and high individual valuation of the environment). Each of these scenarios refers to different types of risk perception within the society. In the "Global Markets" scenario people are short-term planners, who give nature exclusively an aesthetic and use-value. In such a risk-inclined society environmental targets are lax implemented. In the "Strong EU" scenarios it is assumed, that the EU enforces clear directives and explicit regulations in order to achieve sustainability. People are educated to be respectful of regulations and are aware of the need of nature preservation, thus embracing the way towards sustainable development for the sake of future generations. In the "Green Regions" scenario people turn to a greener lifestyle. This implies a change in mentality with respect to the present, which brings about regionalisation, self supply, and community life. Priority is given to environmental issues and nature conservation (overcompliance with the WFD). People are long-term, risk-averse planners, who attempt to minimise environmental risk, even at a high costs.

All three scenarios are developed along six dimensions (Governance, Lifestyle, Social values, Relevance of the EU, Economy and Environment), which are inter-dependent. In figure 5, the qualitative assessment for these dimensions under the different scenarios is represented in an "amoeba graph".

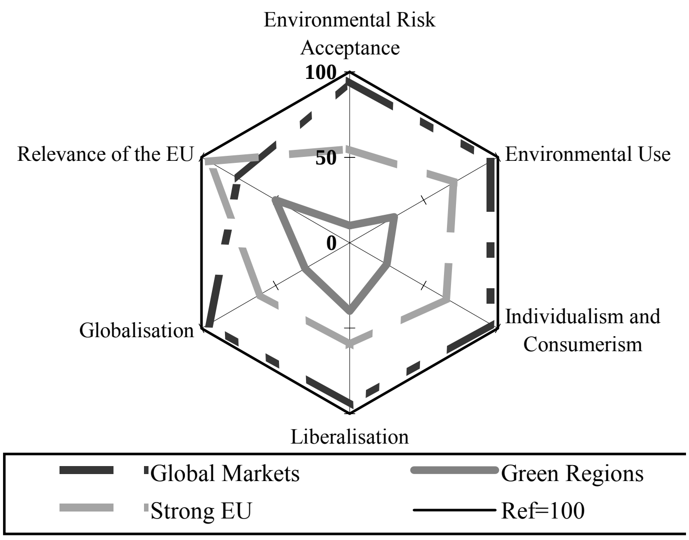

Fig. 5: Scenarios in RebCAT at a glance. Governance is expressed by the degree of globalisation (globalisation, 100 of the scale, and regionalisation, 0 of the scale). As a relevant aspect of lifestyle the environmental risk acceptance of society has been highlighted, relevance of the EU is intended as the degree at which international and regional policy is driven by the EU policy. For social values the focus has been set on individualism (100 of the scale, while community values are set 0 of the scale). For economy the liberalisation of markets has been chosen and finally the environmental use (or abuse) is an indication of the perception of and value given to the environment.

The different political issues, lifestyles and social values characterising each scenario will exert different pressures on the environment. In this context the ecosystems will experience different (intensities of) pressures (Colijn et al. 2002), and, consequently, different impacts on their integrity and functionality, thus implying different environmental risk for society. As a result of this scenario storylines, related policy targets, expressed as nutrient reduction targets were defined (table 1), which formed the input for the catchment model in order to identify measures that need to be implemented, if these targets should be achieved. The coastal model used these targets and the loads associated to them as input in order to calculate the effects on the coastal ecosystem.

Scenario	**Nitrogen/Phosphorus**
Standard Run	100%
Bussiness as Usual (BAU), Global Markets	80 %
Policy Targets (PT), Strong EU	70 %
Deep Green (DG), Green Regions	60 %
Pristine Conditions (PC) (without population)	10 %

Tab. 1: Target levels for nutrient loads at the interface between estuary and coastal zone compared to 1995 in RebCAT estimated out of the scenario storylines. According to Behrendt et al.(2002) the 10% level of the 1995 nutrient load of the Elbe represents background (pristine) conditions, assuming forests in the whole Elbe catchment.

5 Coastal Impact Assessment

5.1 The ecosystem model ERSEM

The ecosystem model ERSEM (European Regional Seas Ecosystem Model) was developed to simulate the ecosystem dynamics of the North Sea. The model simulates the annual cycles of carbon, nitrogen, phosphorus and silicon in the pelagic and benthic food webs of the North Sea. The box model combines hydrodynamic and ecological processes into one model with the same resolution in space and time. The model is forced by irradiance and temperature data, suspended matter concentration, hydrodynamical information for advection and diffusion, data on atmospheric nutrient input to the North Sea as well as by inorganic and organic river load data. The biological part of the model consists of an interlinked set of modules, describing the biological and chemical interactions between the state variables. A general description of the model is given by Baretta *et al.* (1995) and Lenhart (1999).

The models cover an area of 577 620 km2 and a volume of 51047 km3 in total. The northern and central parts of the North Sea are divided into 1 by 2 degree boxes. For resolving the horizontal gradients in the coastal areas the spatial resolution was increased to boxes of 0.5 by 1 degree. In this study the ERSEM boxes 78, 69 and 59 were chosen thus covering the Elbe estuary as well as the northern part of the German Bight and Wadden Sea (Figure 6). This coastal area is nearly identical with the OSPAR regions O-II-3D of the Greater North Sea. More details on the model setup and the model forcing can be found in Lenhart et al., (1997) and Lenhart (1999).

ERSEM has been applied within the Elbe case study for the simulation on the response in the coastal zone caused by changing nutrient loads from the river management strategies. The idea was to test the reaction potential or the model responsiveness (OSPAR 1998) of the North Sea ecosystem under the three scenarios described above. Before the reduction scenarios have been simulated, the standard run for the year 1995 had to be obtained and documented, since the standard or reference run and will form the basis against all later scenario simulations have to be compared.

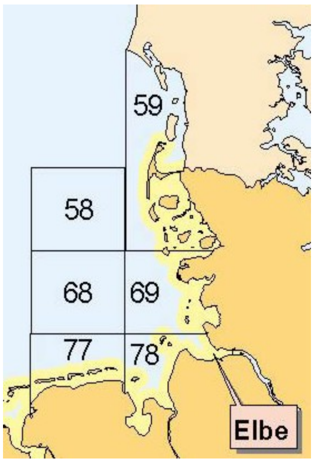

Fig. 6: ERSEM boxes in the coastal zone used for the Elbe case study. The Elbe box represents the volume based sum of the ERSEM boxes 58, 59, 68, 69, 77 and 78 taken together.

For the scenario calculations model runs using the policy targets from the scenarios as input were performed. Following a rough assessment of nutrient load reductions in 10%steps the following 3 scenarios with a load reduction down to 10%, 60%, 70% and 80% of the reference year 1995 have been investigated in more detail. The key parameters were harmonised with those used during the ASMO workshop:

- Mean winter DIN concentration
- Mean winter DIP concentration
- Mean winter DIN / DIP ratio
- Mean winter DIN / Si ratio
- Mean winter DIP / Si ratio
- Timing of spring bloom
- Mean Chl-a concentration
- Mean summer Chl-a concentration
- Net Primary Production
- Diatom/Non-Diatom ratio

In addition time series for DIN, DIP, Chlorophyll a, diatoms, flagellates and diatoms were analysed. A full description of the scenario simulations is given in Lenhart 2004.

5.2 Interpretation of model results

In RebCAT 1995 serves as the reference year. Therefore, the forcing data have been calculated for this year. Interpreting the data, it should be realised, that during the reduction scenarios only the nutrient input of the river Elbe has been reduced, while the nutrient load of the other tributaries to the North Sea has been kept constant on the 1995 level.

This on the one hand explains to a certain extent, that even drastic reductions of the nutrient loads from the Elbe cause comparatively small changes of the ecological parameters in the Elbe box. These results hint at the need to reduce the riverine nutrient load from the other tributaries as well. But for the purpose of this paper the case study will suffice to demonstrate the suggested evaluation strategy based on ecosystem integrity as outlined before. Figure 7 shows for primary production distinct changes in the German Coastal Zone induced by reduced riverine nutrient load. While box 78 is the most sensitive one of the analysed boxes, the Elbe box represents the average situation. But still it has to be taken into account that the model only mirrors a selective view of the studied ecosystems. Thus comparative monitoring activities are required to validate the model outcome. Similar changes can be observed for diatom/non-diatom ratios.

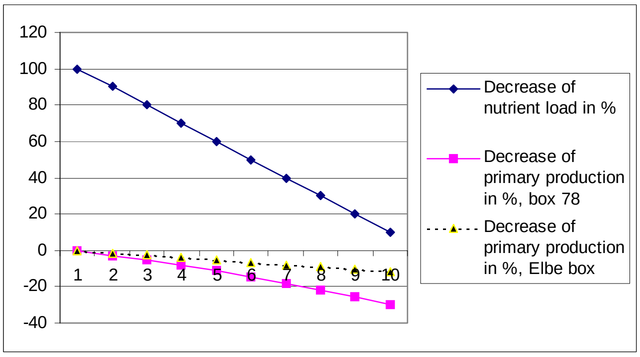

Fig. 7: Relative decrease (1995=100) of primary production in different areas (ERSEM boxes) of the German Bight due to decreasing nutrient loads from the Elbe.

The next level of this analysis is to link the concept of self-organising capacity of ecosystems with the data and information available about ecology in the coastal zone as response on different levels of human impact. The calculated values for the Elbe box mirror, that nearly all indicators are sensitive to reduced nutrient loads from the Elbe, but to a different extent. Obviously the interactions of the coastal ecosystem are changing from a linear nutrient reduction into non-linear effects, thus pronouncing the need to analyse the overall functioning of the ecosystem too (Windhorst et al 2004).

In order to indicate the influence of these indicators on the self organising capacity and the relative impact caused by the different reduction scenarios it is necessary to transform the calculated values into relative numbers (Windhorst et al. 2004). The first step was to compute the maximum change between the absolute values for the Standard year 1995 and the 10% level assumed as conditions without human impact. In a second step the relative change in % of the values modelled for the reduction scenarios, taking the maximum distance as 100% were calculated. In order to indicate the change of the storage capacity and the matter output out of the Elbe box it is assumed, that the values for nitrogen and phosphorus are of equal importance. Thus, the modelled and transformed values were summed up and divided by two in order to get one indicator value. As a result the diagram shown in fig. 8 can be drawn.

The diagram shows that in the selected case study the storage function of the coastal ecosystem changes in relative terms more than the other indicators. This confirms the theoretical argumentation, that this indicator could reveal essential information about the functioning of the coastal ecosystem.

But still it has to be analysed to which extent the different reactions of the selected indicators explain an overall change of ecological quality of the coastal ecosystem, which can be interfaced with an economic and ecological risk perspective. Figure 9 only shows a relative change of ecological risks according to the modelled reductions of riverine nutrient loads. The 100% scale for the ordinate was chosen because it allows to visualise the maximum distance of the ecological status between the reference year and the assumed pristine conditions and the relative change of the ecological status, which can be achieved by the selected scenarios.

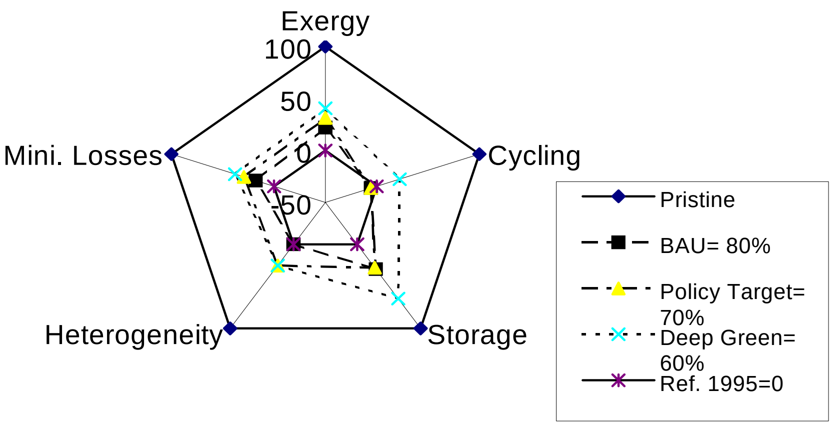

Fig 8: Relative distance of different ecological states in the coastal zone to assumed pristine conditions according to different reduction scenarios of nutrients loads of the river Elbe using the following indicators from Tab. 2: exergy = primary production, cycling = turnover of winter nutrients, storage = (sediment input – sediment output), heterogeneity = diatom/non-diatom ratio, minimising losses = nutrient output out of the box (Windhorst et al. 2004).

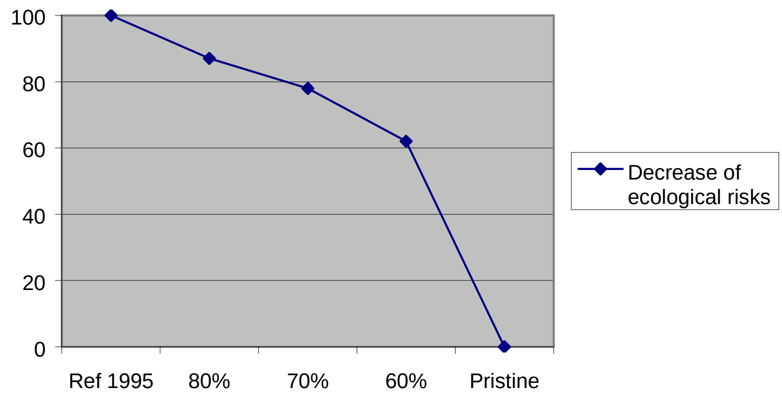

Fig. 9: Change of ecological risks in the Elbe box in correspondence to different reduction scenarios of riverine nutrient loads (1995=100%, Pristine=10%) (Windhorst et al. 2004).

Figure 9 shows that the overall change of the ecological status of the coastal zone is increasing with lower riverine nutrient loads, which goes apart with lower risks of ecological hazards. The figure also allows to indicate an overall ecological benefit, which could be achieved by economic endeavours in the catchment to reduce nutrient losses. But under the constraints described by Behrendt et al. (2002) and the selected scenarios in this case the ecological status of the coastal zone would stay even in the best cast case – the deep green scenario – far away from the assumed pristine conditions.

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