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Perspectives on Eutrophication Abatement in the Baltic Sea

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Abstract

Eutrophication is a serious ecological problem in the Baltic Sea and has negative economical consequences for the coastal zones. Applying a 3 D-biogeochemical model, we compare different eutrophication abatement strategies for the Baltic Sea and try to answer the question about the future of the Baltic Sea. Coastal waters respond with a fast decrease of algal biomass to a 50 % nutrient load reduction. In the open Baltic Sea a reduced spring bloom is compensated by increasing cyanobacteria (blue-green algae) blooms in summer and effects are visible only after several years. Increased cyanobacteria blooms might occur only in the transitional period and could finally, after decades, result in lower concentrations. However, a 50 % nutrient load reduction in general has only minor effects on phytoplankton, independently which strategy is used. Model results suggest that eutrophication abatement measures have not the expected effect. Instead, increasing harmful algal blooms might become a serious threat for a sustainable coastal development during the next decade.

1. INTRODUCTION

How does the future of the Baltic Sea and its coastal waters look like? Eutrophication is one of the major problems in coastal waters in general and in the Baltic Sea especially. It is a large scale problem and in most cases regional coastal zone management approaches are not suitable for the management of eutrophication. To combat eutrophication in the Baltic Sea an approach for the entire Baltic drainage basin is needed. Regional coastal water management needs a Baltic Sea management strategy and appropriate large-scale tools for decision support and the evaluation of measures. We present results of a large scale 3D-eco-systemmodel that can be regarded as a suitable decision support model for eutrophication combat in the Baltic Sea. We compare the impact of two 50 % nutrient reduction strategies on the Baltic Sea The first strategy assumes a proportional 50 % nutrient reduction in every bordering country, as suggest by HELCOM. The second approach is based on existing socio-economic calculations by Gren (2000) suggesting an optimal, cost-effective 50 %-nutrient reduction.

In previous studies the general impact of a 50% nutrient reduction (Neumann et al. 2002), the short term effects on the Baltic coastal waters (Neumann & Schernewski 2001) and implications for river basin management (Schernewski & Neumann 2002) were analysed. In this study we focus on differences of the eutrophication combat strategies in two regions of the Baltic Sea, the Oder and the Vistula estuary and analyse the gradients between coastal waters and the open Baltic Sea.

Of special interest is the question how fast the coastal waters and the Baltic Sea react after a load reduction. Finally, we discuss the practical problems of Baltic Sea eutrophication and the implications of possible future water quality developments for Integrated Coastal Zone Management especially tourism development.

Figure 1: The central Baltic Sea (Baltic Proper) and the location of Vistula and Oder estuary.

2. EUTROPHICATION IN THE BALTIC SEA

The Baltic Sea is one of the world wide largest brackish water bodies (412.000 km²) with a water residence time of about 25-30 years, a drainage basin of 1,734,000 km² and a population in the drainage basin of about 85 millions. In the late 80's about 70,000 t/a phosphorus and 917,000 t/a nitrogen were discharged into the Baltic Sea (FEI 2002). The result is severe eutrophication, especially of the coastal waters.

The most important rivers with respect to water discharge are Newa (77,6 km³/a, Russia), Vistula (33,6 km³/a, Poland), Daugava (20,8 km³/a, Latvia), Nemunas (19,9 km³/a, Lithuania and Russia) and Oder (18,1 km³/a, Poland and Germany). The Vistula river contributes about 15 % of the total phosphorus and about 19 % of the total nitrogen riverine discharge into the Baltic Sea (Andrulewics & Witek, 2002).

The contribution of the Oder river is about 9 % to the total riverine load into the Baltic Sea. Both rivers are main polluters of the Baltic Sea and contribute about 50 % of the total load into the Baltic Proper, the central Baltic Sea. The coastal lagoons suffer most from ongoing high nutrient discharges and show high nutrient concentrations and a high phytoplankton biomass. With increasing distance to the shore the nutrient concentrations are decreasing very much. Figure 2 shows this for the Oder estuary.

The Oder river discharges its load first into the Oder (Szczecin) Lagoon and then further into the Baltic Sea (Pomeranian Bay), where fast mixing and biogeochemical processes reduce the concentrations.

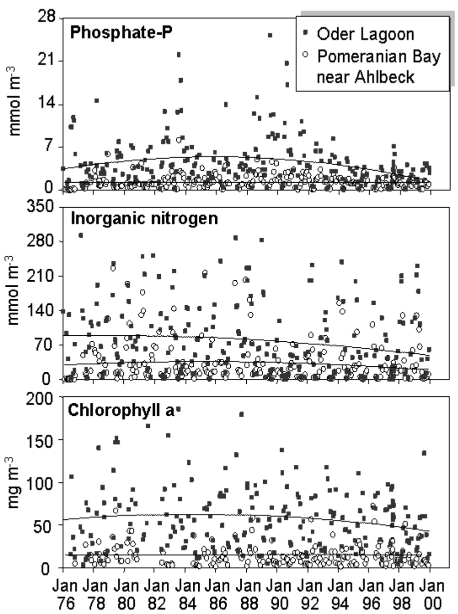


Figure 2: Phosphate, inorganic nitrogen and chlorophyll a concentrations (indicator of algae biomass) in the central Oder Lagoon (Kleines Haff) and in the Baltic Sea near Ahlbeck (monthly measurement). The pronounced annual cycle of the concentrations cause the scattered data. The solid regression curves give a certain impression of trends during the last decades. The data were provided by the LUNG Mecklenburg-Vorpommern (LUNG) (Schernewski & Sterr 2002).

The consequences of eutrophication are an increased frequency and spatial coverage of excessive algal growth (algal blooms) with discoloration of the water and foam formation as well as oxygen depletion in deeper water bodies, a reduction of water transparency followed by a decrease of depth and distribution of perennial macrophytes. Shifts in fish and benthic fauna as well as changes in the food-web are observed, too.

Photo 1 and 2: Cyanobacteria bloom in the Oder Lagoon as well as in the Greifswalder Bodden (Baltic Sea) in summer 1999.

The first algal bloom in the Baltic Sea in spring is characterized by varying portions of dinoflagellates and diatoms. These blooms can form a high algal biomass, reduce water transparency. Potentially toxic species can be involved.

Especially in shallow coastal waters, spring blooms of diatoms sometimes cause severe oxygen depletion resulting in fish and mussel kills. Photos 3 and 4 show examples from the Oder Lagoon.

Most problematic are algal blooms during summer, when human leisure activities along the coasts are most intensive. In the central Baltic Sea cyanobacteria blooms are a common feature in summer. Potentially toxic species of *Aphanizomenon, Anabaena* and mainly *Nodularia* are dominating and can cause large accumulations on the water surface.

In 1982, 1983 and 1984 more than 30,000 km² water surface were covered by algae accumulations. In 1991, 1992 or 1993 between 40,000 km² and more then 60,000 km² (Kahru et al. 1994) or up to 30 % of the central Baltic Sea area, the Baltic Proper, were affected.

Photo 3: Mussel kill due to oxygen depletion above the sediment. Fermentation gases caused the floating of the still closed shells in the Peene Strom, an inner coastal lagoon of the Baltic Sea (provided by M. Zettler).

Photo 4: Fish kill due to oxygen depletion during an intensive algae bloom in May 2000 in the Oder lagoon.

3. EUTROPICATION COMBAT STRATEGIES

Already in 1974, the nine riparian states (Denmark, Sweden, Finland, Russia, Estonia, Latvia, Lithuania, Poland and Germany) signed the Helsinki Convention. To improve water quality, the states agreed to undertake all appropriate measures to minimise land-based pollution to the Baltic Sea. Goal of the Ministerial Declaration of 1988 was a reduction of the nitrogen and phosphorus load by 50 %. In a recently published report, the Finnish Environment Institute (FEI 2002) evaluated the nutrient load reductions into the Baltic Sea between the late 80's and 1995. Altogether the total nitrogen as well the phosphorus load was reduced by 35 %. A fast reduction was observed mainly in countries with a transitional economy.

Poland and Russia alone contributed about 155,000 t or nearly 50 % of the total load nitrogen reduction into the Baltic Sea. The same is true with respect to phosphorus. Russia and Poland reduced their P-load by about 11,900 t or nearly 50 %, as well. Despite that, Poland remained by far the most important N and P pollutant for the Baltic Sea. The nutrient load reduction showed already positive effects in coastal waters but the phytoplankton concentration in the central Baltic Sea is still not affected, Figure 3.

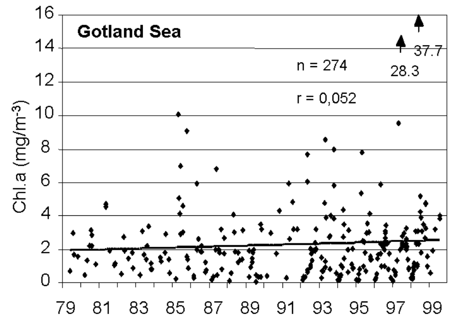


Figure 3: Trend of the Chlorophyll a concentrations in the Gotland Sea during lthe last 20 years (averages from 0-10 m) (after Wasmund et al. 2000).

The first 35% reductions of nitrogen and phosphorus were achieved within a period of only 7 years. The experience in other regions shows that further reductions are much harder to obtain. There are already doubts, whether a 50% reduction of nitrogen especially from diffuse sources in the Baltic can be reached even until 2005. To obtain the 50% nutrient load reduction is especially problematic for all countries, which yet meet high water quality standards and have already realised load reductions during the early 1980's. Therefore alternatives are under discussion.

4. COST-EFFECTIVE MANAGEMENT

The riparian countries around the Baltic Sea show pronounced differences in land use, economy, intensity of agriculture, population density and especially the quality and efficiency of sewage treatment. The agreed proportional 50%-load reduction from the territory of every country is a political goal without taking the total costs for the measures into account. We call it the proportional approach. The alternative approach suggested by Gren (2000), has the goal to meet the 50%-nutrient load reduction at minimum total costs. This implicates, that nutrient load reduction takes place in countries and drainage basins where it shows its highest cost-efficiency. We call this the cost-effective approach.

Background for the calculation of the cost-effective approach is the awareness, that the marginal costs of abatement measures are not equal between the riparian states. Marginal costs are defined as the increase in costs to reduce the nutrient load of nitrogen and/or phosphorus to the Baltic Sea by 1 kg. To calculate the scenario, Gren (2000) identified all reduction options and their location, quantified the reduction effect on nutrient loads to the Baltic Sea and calculated the marginal costs for all options.

The marginal costs of different measures reducing the nitrogen load to the Baltic Sea, for example, vary very much between different types of sources. To reduce 1Kg N-load from agriculture in Germany costs between 3-15 Euro, from sewage plants 3-8 Euro from wetland 3.5 Euro and from atmospheric deposition 24-450 Euro. Similar variations are obvious between different countries. For a reduction of the nitrogen load by 50% wetlands, agriculture and sewage plants have to contribute about the same share. This is different for phosphorus, where improvements of sewage plants are most important and alone can contribute 80% to the reduction. Most pollution takes place from the territory of the eastern European countries and in general it is cheapest to reduce the nutrient load there.

The optimal reduction of nitrogen and phosphorus causes only 23% of the costs of a proportional reduction and has therefore serious economic benefits (Gren 2000). The two approaches have different consequences for the Baltic Sea. The intensity of the load reduction varies between the regions and implies regional differences with respect to water quality in the Baltic Sea.

5. MODEL APPLICATION

A 3D-circulation model with biochemical module was applied for the simulation of the impacts of the two strategies. The circulation model is based on the Modular Ocean Model MOM2.2 and covers the entire Baltic Sea. A horizontally and vertically telescoping model grid with high horizontal resolution in the south-western Baltic (3 nautical miles) and increasing grid size towards north and east was applied. The first 12 vertical layers possess a width of 2m. The vertical thickness of deeper layers increases with depth. Towards the North Sea (Skagerrak) an open boundary condition is applied. An atmospheric boundary layer model derives the ocean surface fluxes from measured and calculated meteorological data. For detailed model description refer to Neumann (2000).

The chemical-biological model consists of 10 state variables (ammonium, nitrate, phosphate, 3 phytoplankton groups, detritus, zooplankton, oxygen and sediment).

Altogether 11 processes are taken into account (N-fixation, denitrification, nitrification, atmospheric input, algae respiration, algal mortality, nutrient uptake by algae, zooplankton grazing, mineralization, sedimenta-tion and resuspension) In most parts of the Baltic Sea, nitrogen has to be regarded as the limiting element for phytoplankton production. The model therefore is focused on a proper description of the nitrogen cycle. The chemical-biological model code is embedded as a module in the circulation model and linked via the advection-diffusion equation. For a detailed model description and applications of the 3D-ecosystem model see Neumann *et al.* (2002) and Neumann & Schernewski (2001).

Fresh water supply and nutrient load of the fifteen largest rivers with their proper spatial location are taken into account as a model input. The rivers are regarded as point sources, which carry not only the measured river nutrient load itself, but represent additional diffuse and smaller point sources of the surrounding area. The 15 rivers therefore cover the entire diffuse and point source load to the Baltic Sea. Atmospheric deposition is kept separately. A period of 4 years (January 1980 – December 1983) was simulated for both nutrient reduction strategies as well as a control run with no nutrient reduction. The choice of this period was due to the availability of a comprehensive and reliable data set of river loads as well as atmospheric deposition for the entire Baltic.

Table 1: River loads 1981 [kt a-1] used as input in the 50% cost-effective and proportional reduction simulations (Neumann & Schernewski 2001)

River system	Country	Phosp.		Nitrogen	
		Opt	Prop	Opt	Prop
Kemijoki	Finland	1.4	1.1	11.8	10.0
Lulealv	Sweden	0.6	0.5	5.9	5.1
Angermansalv	Sweden	1.0	0.8	16.1	13.8
Umealv	Sweden	0.7	0.4	15.6	13.5
Kokemäenjoki	Finland	0.9	0.7	11.0	9.3
Narva	Est./Rus.	0.8	0.5	10.2	10.7
Neva	Russia	1.1	1.4	26.3	27.4
Oder	Poland	3.4	3.9	56.8	59.2
Vistula	Poland	2.4	2.7	77.8	81.0
Nemunas	Lithuania	1.7	1.7	24.9	26.0
Helgean	Sweden	0.1	0.1	2.8	2.4
Eman-Motal	Sweden	0.4	0.3	5.7	4.9
Maelaren	Sweden	0.0	0.0	0.4	0.3
Daugava	Latvia	2.3	2.6	45.9	53.4
Goetaaelv	Sweden	0.6	0.5	16.4	14.1

The first simulation assumed a proportional reduction of every load by 50 %. The second simulation was based on the optimal cost-effective nutrient reduction scenario. In both cases the absolute load reduction of nitrogen and phosphorus to the Baltic Sea was similar, but the spatial distribution of the nutrient load differed. Gren (2000) suggested the following allocation of cost-effective reductions of phosphorus and nitrogen: Denmark 60% P / 46% N, Estonia 10% / 54%, Finland 32% / 41%, Germany 55% / 15%, Latvia 55% / 66%, Lithuania 52% / 58%, Poland 58% / 59%, Russia 65% / 57%, Sweden 19% / 42%. This information was used to calculate modified rivers loads for the model simulations (Table 1). Due to differences in methodology and the data basis some differences between our data and Gren (2000) occurred.

6. SIMULATION RESULTS

The simulation results for the surface layers of the Baltic Sea after 4 years of simulation were reported earlier (Schernewski & Neumann 2002). Basic results are briefly outlined. Results showed that after four years simulation time, the 50% cost-effective nutrient load reduction simulation caused pronounced differences in surface concentrations. The annual average nitrogen (dissolved inorganic N) concentrations in the south and south-east Baltic Sea were reduced by nearly 50% and near Sweden, the reduction of the nitrogen concentrations was below 10%. The phosphate reduction was less pronounced. Reduced nutrient loads and concentrations in the Baltic Sea caused an average decline of Chlorophyll concentrations, which is an indicator for algae biomass. With about 15% the highest decline in chlorophyll concentrations was observed in the south-eastern Baltic Sea. Nearly no effect was visible along the Swedish coast.

In average the chlorophyll concentration were reduced by less than 10%. Altogether the 50% nutrient load reduction did not cause a similar reduction of the algae biomass, but the different algae groups behaved in a different manner.

Diatoms showed a strong response to nutrient reduction. The diatom biomass along the entire south-eastern Baltic Sea showed a drop of more than 30%. The situation with respect to blue-green algae was opposite. Reduced nutrient loads favoured the development of blue-green algae in the entire Baltic Sea. In some parts of the southern and eastern Baltic Sea an increase up to 600 % was observed, Figure 4.

In the following we analyse the temporal development of the concentrations after the load reductions along 2 profiles from the Oder and Vistula river mouth via coastal seas to the central Baltic Sea. The concentrations are always averages of a 15m wide surface water layer.

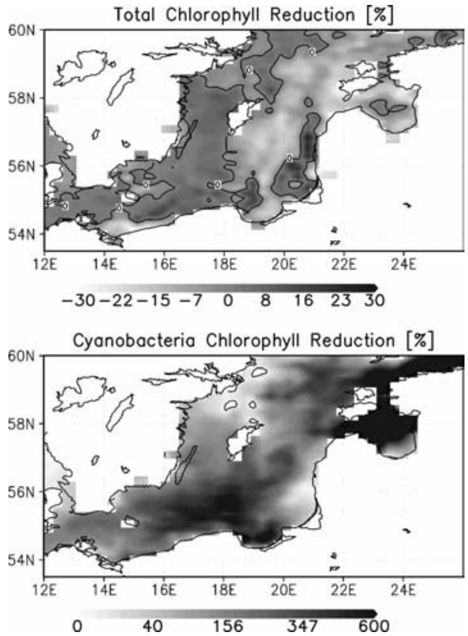


Figure 4: Relative [%] decrease of total chlorophyll a (indicator of algal biomass) and cyanobacteria (Blue-green algal) chlorophyll a concentrations after a reduction of the riverine nutrient load into the Baltic Sea by 50%. The figures show simulation results with the 3D-ecosystem model of the Baltic Sea. (Schernewski & Neumann 2002)

Close to the Oder river mouth, the nitrogen and phosphorus concentrations clearly reflect the 50%-load reduction**,** Figure 5. Differences between the proportional and cost-effective scenario are small.

In the Pomeranian Bay decreasing nitrogen concentrations follow the load reduction but after 4 years the concentrations in all scenarios are more or less alike. About 100 **K**m towards the open Baltic Sea, in the Arcona Sea, no pronounced differences between the scenarios are visible with respect to nitrogen. Even 4 years after the nutrient load reduction central parts of the Baltic Sea are not affected.

The phosphorus concentrations in the Pomeranian Bay and the Arcona Sea show one special feature: despite the load reduction an increase in phosphorus concentrations takes place in spring. In the remaining time the concentrations are slightly lower. The chlorophyll a profiles in front of the Oder river (river mouth, Pomeranian Bay and Ascona Sea) show some reductions due to the 50% load reduction**,** Figure 6. The reasons are less intensive algal developments in spring. This relative effect is most pronounced in the Pomeranian Bay. But one has to take into account the much higher absolute concentrations at the river mouth.

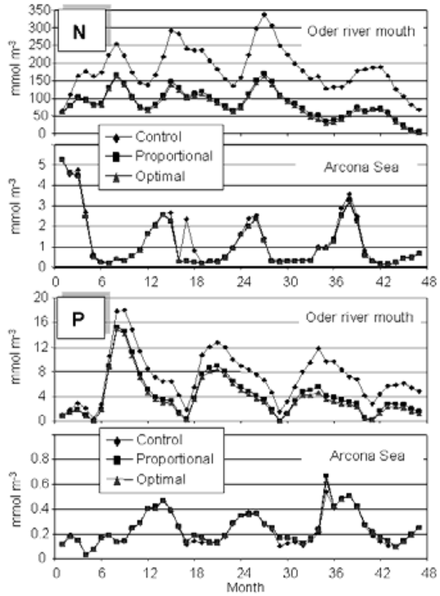


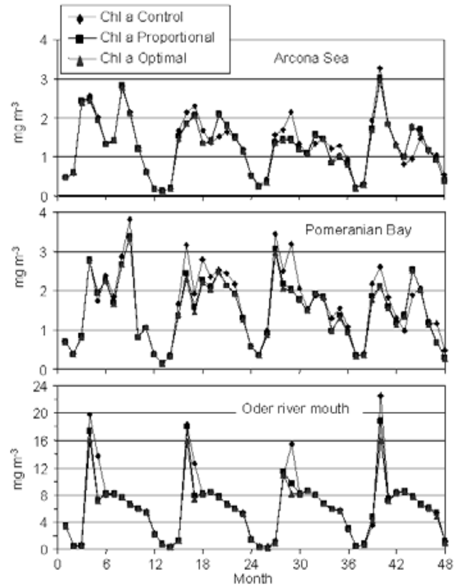
Figure 5: Simulation results with the 3D-ecosystem-modell of the Baltic Sea for 3 nutrient load scenarios: a) no nutrient load reduction (control) b) a proportional 50 % reduction by every country (proportional) and c) the cost-effective 50 %-reduction (optimal). The simulation and load reduction started in January 1980. Shown are vertically averaged nitrogen and phosphorus concentrations in 15 m surface water layers at two stations in the Baltic Sea.

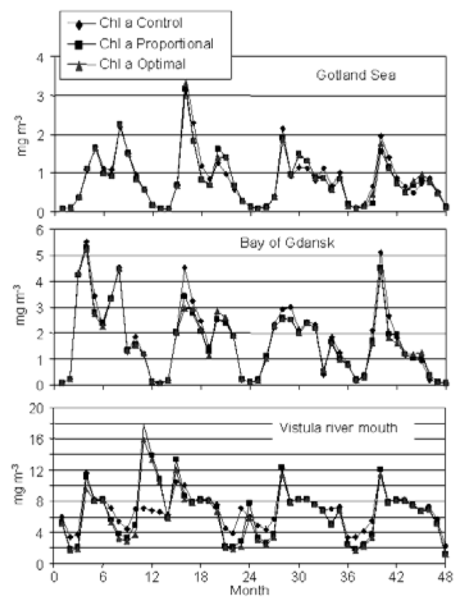
The chlorophyll a profiles in front of the Vistula river (river mouth, Bay of Gdansk, southern Gotland Sea) show reduced chl.a concentrations, too, Figure 7.

Near the Vistula mouth the diatom concentrations are reduced by more than 50% during most of the year. This effect is counteracted by increased flagellate concentrations and not very obvious in total chl.a-concentrations. In the Gotland Sea in some cases the opposite effect is visible: several short term increases of the chl. a concentrations despite a 50% nutrient load reduction.

Altogether, the effect of a nutrient load reduction on algae biomass is only weak and shows no clear intensification over the 4 years

Cyanobacteria contribute less then 25 % to the total annual phytoplankton biomass but are known for intensive blooms in late summer. The model clearly predicts an increase of cyanobacteria concentrations in the open sea (Arcona Sea, Gotland Sea) and the large coastal bays (Pomeranian Bay and Gay of Gdansk). Near the river mouth a decline is predicted (Figure 8).





Figures 6 and 7: Simulation results with the 3D-ecosystem-modell of the Baltic Sea for 3 nutrient load scenarios: a) no nutrient load reduction (control) b) a proportional 50% reduction by every country (proportional) and c) the cost-effective 50%-reduction (optimal). The simulation and load reduction started in January 1980. Shown are vertically averaged chlorophyll concentrations (indicator for algal biomass) along two profiles in front of the Oder and Vistula river. The location of the profiles is shown in Figure 1.

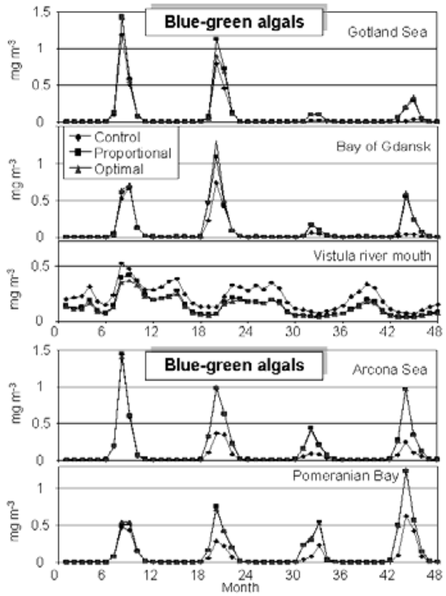


Figure 8: Simulation results with the 3D-ecosystem-modell of the Baltic Sea for 3 nutrient load scenarios: a) no nutrient load reduction (control) b) a proportional 50 % reduction by every country (proportional) and c) the cost-effective 50 %-reduction (optimal). The simulation and load reduction started in January 1980. Shown are vertically averaged cyanobacteria chlorophyll concentrations along two profiles in front of the Oder and Vistula river.

With respect to cyanobacteria, the differences between the load reduction scenarios and no load reduction are increasing from year to year. In the first year the differences are small and become more obvious in the second year. In the third and fourth year only the load reduction scenarios show increased cyanobacteria concentrations in summer. The cost-effective approach shows slightly more pronounced blue-green algae developments off the southern Baltic shore but the differences between both load reductions approaches are not very pronounced.

7. THE FUTURE OF THE BALTIC SEA

Reduced river nutrient load causes reduced nutrient concentrations in the Baltic Sea, but the effect on phytoplankton is not very strong. Due to lower nitrogen availability in the water, the spring development of diatoms is less intensive. In summer, the shortage of nitrogen has negative effects on all phytoplankton groups, with exception of blue-green algae. Blue-green algae are able to utilise atmospheric nitrogen and have the possibility to overcome a shortage of dissolved nitrogen components in the Baltic Sea water. In opposite, their development is favoured, because the development of competing groups is hampered. The reduced spring bloom due to reduced nutrient availability is compensated by an increased summer development of blue-green algae.

Increased cyanobacteria blooms with increased N-fixation would increase the nitrogen load to the Baltic Sea and counteract the eutrophication combat measures. On the other hand, this extra nitrogen might lower the nitrogen limitation and might favour other species again. This example shows that the interactions are complex.. The simulation results suggest, that a proportional reduction of nitrogen and phosphorus at the same time does not have the desired reducing effect on phytoplankton development in the open sea. The taken measures seem to be not suitable to abate eutrophication in the Baltic Sea. A possible solution can be an increased reduction of the phosphorus load. Phosphorus is an element that potentially limits the phytoplankton production in the Baltic Sea. In some regions of the Baltic Sea phosphorus is the most important limiting element. A shortage in dissolved phosphorus in the water cannot be compensated by algae. All groups are affected by a phosphorus limitation more or less in the same manner and the observed shift between different phytoplankton groups is less likely under P-limitation. Additional simulations have to prove, whether alternative management strategies might be more successful.

A box-modelling approach by Wulff (2000) showed that during the first 10 years the nitrogen and phosphorus concentration were reduced by about 25% in the Baltic Proper, when a 50% load reduction was applied. Due to sediment processes and a lack of loss term like denitrification, the decline of phosphorus concentrations shows a higher intertia than nitrogen concentrations. Our simulations are in agreement with these results, but spatial differences are obvious. We presented simulations over a 4 years period. It is likely that after this time, the Baltic Sea is not in a balance again and the results have a preliminary character. The imbalance is partly visible in a shift between phosphorus and nitrogen concentrations. The increased cyanobacteria concentrations might be a result of this imbalance. It is possible that after 15-20 years a stable and lower level of nutrient concentrations with reduced concentration of cyanaobacteria will be reached.

Coastal areas respond fast to a load reduction. Due to an average water retention time of about 25-30 years in the Baltic Sea the central areas adapt slower. However, an interesting aspect of the simulation time series is the strong interannual variability of phytoplankton groups and chlorophyll concentrations. This is well reflected in the data, Figure 3, too. This variability conceals effects of management measures. It is not likely that data will show the effect of the ongoing nutrient load reductions soon. Therefore, models are an important tool for decision support and the evaluation of taken measures.

With respect to the future of the Baltic Sea one has to conclude that the nutrient load reductions might not be that successful as expected and with increasing blue-green concentrations very negative side effects are possible. A modified and realistic vision for the development of water quality in the Baltic Sea as well as a re-evaluation of the management strategy seems to be necessary.

8. COASTAL WATER MANAGEMENT

Integrated Coastal Zone Management (ICZM) became popular during the last decade and the awareness of the necessity of ICZM increased in all European countries. Despite that well defined structures and national ICZM-frameworks are still the exception.

In Germany, spatial planning already covers many aspects of ICZM, but severe shortcomings are obvious: Competences are overlapping and responsibilities scattered, the legislation is sectoral and complex, there are shortcomings in co-operation, communication and public participation and the availability of data and access to information still needs improvements. One largely neglected key issue are coastal waters. At the moment, spatial planning in Germany does not take into account coastal waters and a pronounced division between coastal waters and land exists. Germany is no exception in this respect but more or less the rule.

Photos 5 and 6: Tourism in the Oder Lagoon and on the Baltic Coast of Usedom.

There are multiple, partly unknown and largely uncoordinated uses in and impacts on coastal waters. In Germany, all uses in coastal waters up to 12 nautical miles boundary were recently compiled and displayed in a map. The map shows two important thinks: 1. There is not much room left for further uses and developments (e.g. off-shore windparks) in coastal waters and 2. many problems in coastal waters cannot be presented in a map. Coastal water planning needs a different approach than terrestrial planning. An example are water pollution and eutrophication. Due to changing currents, the state of a water body in a defined region is permanently changing and absconds from mapping in a region plan. Further, the source of a pollution is often located outside a planning region and cannot be solved by local coastal zone management. Large scale management approaches are necessary and have to be linked to regional initiatives

Apart from several larger coastal cities, harbours and industries, the overwhelming part of the German and Polish Baltic coastal zone can be regarded as rural. Southern Baltic coastal zones cover a large variety of types and are attractive, ecologically valuable landscapes. Nature protection therefore plays an important role along the coasts. On the other hand, the long sandy beaches, cliffs, islands and lagoons on the southern coast of the Baltic Sea are attractive for beach and bathing tourism, and millions of vacationers spend their holidays there. Tourism became the major source of in-come, and the tourism industry is still expected to grow. The number of beds in official accommodations along the German Baltic coast was close to 200,000 with about 20 Mio overnight stays in 1998. The situation along the Polish coast is similar. The two coastal regions Pomorskie and Zachodniopomorskie possess a tourist bed capacity of 172,000 with more than 19 Mio overnight stays in 1999. Many well-known tourist regions are located in the estuaries of the rivers Vistula and Oder. A sustainable development of the southern Baltic Coast in most areas means a sustainable development of tourism. Bathing tourism depends on a good water quality. Therefore, sustainable coastal development requires an appropriate management of the eutrophication problem and the Baltic Sea.

Eutrophication and drifting surface accumulations of algae, especially of toxic cyanobacteria, nowadays are not only a nuisance but a real threat for coastal areas and beaches in the entire Baltic Sea. They can cause human health problems and a poisoning of marine and terrestrial animals (birds, fish, cattle etc.) was reported several times for the Baltic Sea. Over 50,000 cases of human poisoning by toxic algae were estimated world-wide (Edler *et al.* 1996).

Another aspect is the publicity effect of an algae bloom. A recent example was an algal bloom (cyanobacteria and diatoms) off the Danish coast in Juli 2001. The algal foam accumulated on the water surface and drifted into Lübeck Bight, were a beach had to be closed for several days. The algae accumulation covered only several hectares and was not a serious problem, but it became an important issue in the local news. Tourism industry was concerned, that bathing and tourism along large parts of the German Baltic Sea coast might be negatively affected simply by the bad news. Therefore, algal blooms can cause serious economic losses not only in fish farms and aquaculture.

Nutrient load reductions have a positive impact on coastal water quality, especially in the vicinity of larger rivers and are therefore recommendable. The possible increase in harmful algal blooms in the open Baltic Sea can become a serious and increasing problem for the coasts in future.

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