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Models as tools in coastal water management: eutrophication of the large, shallow Szczecin Lagoon

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Summary

The water quality of the Szczecin Lagoon (Odra Lagoon) as part of the Odra River estuary is strongly influenced by riverine nutrient loads. We apply an ecological box model of the Szczecin Lagoon to simulate the potential impact of reduced riverine nitrogen and phosphorus loads on phytoplankton biomass. Two different nutrient load reduction scenarios are presented: A 50 % nutrient load reduction suggested by HELCOM and a scenario by Behrendt et al. (2001) with a 34% N resp. 62% P reduction. The model indicates that in the 80's and 90's phytoplankton biomass is controlled mainly by light. Phosphorus is limiting during short periods in spring and nitrogen in summer periods. After a load reduction, nutrients gain importance and the time spans with nutrient limitation are extended. The seasonal limitation pattern remains the same and the lagoon does not switch to a real nutrient controlled system. The load reduction suppresses chlorophyll concentrations only to a limited extend, but the algae blooms during summer (often blue-green algae) are strongly diminished. This has great practical importance for summer tourism. Due to the stronger phosphorus load reduction in the second scenario, the spring bloom is reduced to a higher degree. According to the model, even the nutrient load reduction after Behrendt et al. (2001) will keep the lagoon in a eutrophic to strong eutrophic state. However, due to the simple model structure the results are connected to uncertainties.

1 Introduction

The Odra (Oder) River belongs to the largest rivers entering the Baltic Sea, carries high nutrient loads and effects the water quality of the entire estuary and the coastal sea. The Szczecin (Oder) Lagoon, located at the German/Polish border (Fig. 1), is the key element of the Odra River estuary. It is a shallow coastal lagoon with an average depth of 3.8 m. The total area of the lagoon is 687 km^2 and it consists of two main parts - Kleines Haff and Wielki Zalew. The large Odra river catchment (120.000 km²) is densely populated (13 Mio. inhabitants), heavily industrialized, and arable land covers about 47 % of its total area. Over the past 50 years, eutrophication of the lagoon waters was observed as the result of increased anthropogenic influence in the Oder river drainage area. From man's perspective, many negative changes took place in the Szczecin Lagoon ecosystem, like intensive phytoplankton blooms or oxygen depletion above the sediment. During summer intensive algal blooms often form a thick green layer as well as foam on the water surface.

Toxic blooms of blue-green algae, mainly *Microcystis aeruginosa Kűtz.* have also been observed and several cases of animal toxication have been reported in the inner coastal waters. Beaches were closed and bathing prohibited as a consequences of the algae blooms.

As is the case for most coastal regions of the Baltic Sea, summer tourism has a pronounced influence of on the local economy of this region (Schernewski & Sterr 2002). Ongoing growth of tourist industry is regarded as the important possibility to overcome economic problems both, on the German, and the Polish side. Especially for the towns and villages located in the inner part of the Odra estuary, along the Szczecin Lagoon coast, water quality problems are, or at least can be obstacles for economic development. It is therefore important to assess the possibilities of the water quality improvement.

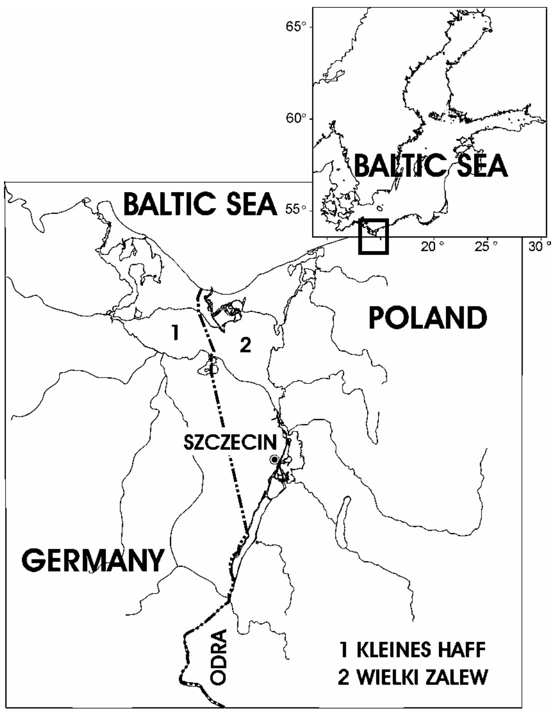

Figure 1 The Odra Rover estuary with both parts of the Szczecin Lagoon (Kleines Haff and Wielki Zalew).

We assume that the most important measures to decrease phytoplankton blooms and increase water quality in the Szczecin Lagoon are reductions of the nutrient input from its drainage basin, mainly from the Odra River catchment, which covers over 90% of the entire lagoon catchment. We present an application of an ecological box model of the Szczecin Lagoon. The model was developed as a tool for the analysis of the impact of riverine loads and internal processes on the water quality of the lagoon in a long-term perspective. Our aim is to simulate and analyse the possible effects of the nutrient load reduction scenarios on the phytoplankton growth and the trophic state in the lagoon.

2 Nutrient load reduction scenarios

During the past two decades Baltic wide initiatives were launched in order to enforce reduction of phosphorus and nitrogen loads discharged to the Baltic Sea. The most important initiative was undertaken in 1988 by the Ministers of environmental protection of all Baltic Sea countries. It was agreed within the so called “Ministerial Declaration” that every country should reduce its loads by 50%, as compared to the load of the late 1980’s. Evaluation of nutrient load reduction conducted by Helsinki Commission (HELCOM) revealed large regional differences (Lääne et al. 2002), but in most cases reduction targets have not been met: the P-loads altogether decreased by 39 % and for the N loads a total reduction by 30 % can be assumed. The evaluation report reveals that Poland did not meet the 50 % reduction aim, too (Jarosinski 2002). In Poland, the point sources loads of phosphorus and nitrogen were reduced by only 23 % and 24 % respectively, and from diffuse sources by 30 % and 10 %. About 90 % of the Odra catchment is located on Polish territory. The reduction aim was not met in the Odra catchment, too and it can be assumed, that the achieved reduction during the last decade is close to the data for entire Poland.

Reduction of nutrient loads from diffuse sources is more comprehensive and takes longer than reduction from point sources. The long retention time within the drainage area prevents a fast reduction of river loads despite considerable success in the reduction of emissions e.g. fertilisers application. The main sources for phosphorus and nitrogen are different. In the Odra catchment, about 62 % of the phosphorus load but only about 37 % of the nitrogen load had their origin in point sources (Behrendt et al. 2001). Different measures are needed to eliminate the two compounds. Different measures take different time, have a different efficiency, vary in the costs and make a similar reduction hard to obtain.

Behrendt et al., (2001) formulated a possible reduction scenario in the Odra drainage area based on a real achievable reduction in phosphorus and nitrogen emissions from the drainage basin as compared to the period of 1993-97 emissions. In the maximum reduction scenario it is assumed that P-emissions of point sources and urban areas are reduced by 77% and 80% respectively. This would require the introduction of P-free detergents, the complete connection of cities and towns (>2000 inhabit.) to waste water treatment plants as well as a sufficient storage volume. The treated sewage water has to meet EEC Directive 91/271. With these measures fully implemented, a reduction of total P-emissions by 62% would be possible.

For nitrogen the highest reduction is expected if cities and towns (>2000 inhabitants) in Poland are connected to waste water treatment (meeting the 91/271/EEC Directive) combined with a reduction of diffuse emissions. Background for the diffuse load reductions is the “Best Management Practice” in Polish agriculture. The maximum achievable total N-emissions reduction rate was calculated to be 34% (Behrendt et al. 2001), which is less than 50% demand by “Ministerial Declaration”.

The 50 % nutrient load reduction after HELCOM (scenario 1) as well as the 62% / 34% reduction after Behrendt et al. (2001) (scenario 2) are applied and their impact on the water quality of the lagoon is simulated with an ecological model. In the latter scenario, we assume that reduction suggested by Behrendt et al. (2001) in P- and N-emissions from the drainage will result in the identical reduction of the riverine loads.

3 Impact of nutrient load reduction scenarios in the Szczecin Lagoon

The dynamic ecological box model used for simulation consists of two boxes representing two parts of the lagoon Wielki Zalew and Kleines Haff. The model consists of following state variables: DIN, PO_4, nitrogen and phosphorus in detritus (suspended organic matter), nitrogen and phosphorus in the sediment and one phytoplankton group. The model covers the dominant internal nutrient transformation processes: nutrient uptake by phytoplankton, mineralization of nutrients, sedimentation, and denitrification of nitrogen from water and sediment as well as burial of nutrients in sediment. All processes are described based on existing knowledge on nutrient cycling and phytoplankton growth in this brackish water ecosystem. Zooplankton was considered to be of minor importance in the lagoons nutrient cycling and is represented in the model only as increased mortality ratio in summer months. The nutrient flux from the sediment is based on the simple assumption that organic matter deposited on the bottom is mineralized depending on the temperature.

The model is driven by external forces such as the seasonal changes of light and temperature, the nutrient loads discharged with the Odra River and from the immediate lagoon drainage area. At the present stage the model does not take into account intrusion of Baltic Sea water. The internal time scale of the model is one day. The model was validated against data for the period 1982-97, obtained from the regular monitoring programs carried out in Wielki Zalew by the Westpomeranian Inspectorate of Environmental Protection (WIOS in Szczecin/Poland) and in the Kleines Haff by the Landesamt für Umwelt, Naturschutz und Geologie Mecklenburg-Vorpommern (Germany). The simulation of phytoplankton growth in the Wielki Zalew and Kleines Haff was carried out for the period 1982-1997. In a preceding first step the general performance of the model was tested in comparison with measured data. The simulated and the measured data are generally well in agreement (Fig.3 and 4). Both scenarios are applied in the eastern part of the lagoon (Wielki Zalew), which is under much stronger influence from the Odra River than the western part – the Kleines Haff.

The 50 % nutrient load reduction scenario suggested by HELCOM refers to the period 1982-1989. The simulation takes into account weather conditions and data for water discharge of 1982-1989, but the Odra river load of nitrogen and phosphorus from this period was reduced by 50 %. In the scenario suggested by Behrendt et al. (2001), the simulation refers to the period 1990-97. Weather conditions and water discharge data of 1990-97 were used and the Odra river load of nitrogen and phosphorus was reduced respectively. The comparison of the nutrient loads discharged from Odra drainage area to the eastern part of the Szczecin Lagoon according to both reduction scenarios are presented in Figure 2.

Phytoplankton concentration, expressed as Chl_a, is the most important indicator for eutrophication and reflects the effectiveness of a nutrient load reduction. In both scenarios, the reduction of riverine nutrient loads has immediate effects in the Wielki Zalew. The 50 % reduction in the first scenario causes an annual average chlorophyll reduction of 22 % already in the first year (Fig. 3). In the following years the chlorophyll reduction is steadily between 22 and 0 %. One basic result of this simulation is that a 50 % reduction of the nutrient input causes only a minor reduction of phytoplankton concentration. Systematic changes in the seasonal course of phytoplankton development are not very obvious, but the diatom spring bloom is less affected by the nutrient reduction. The suppression of the algal growth during summer is higher after a load reduction.

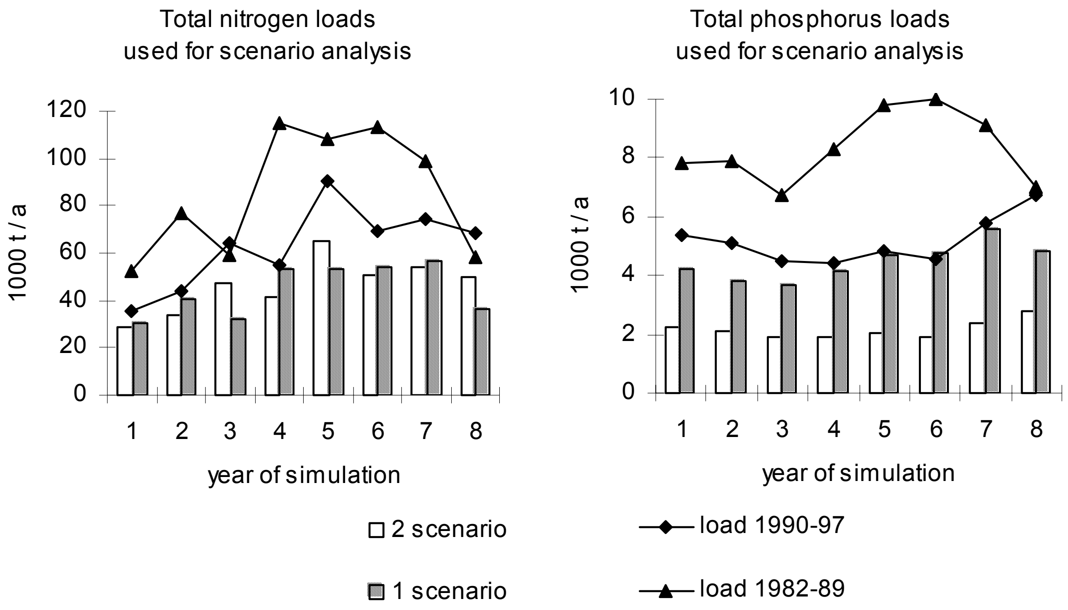

Figure 2 Nutrient loads discharged from the Odra River into the eastern part of the Szczecin Lagoon (Wielki Zalew) in reduction scenarios.

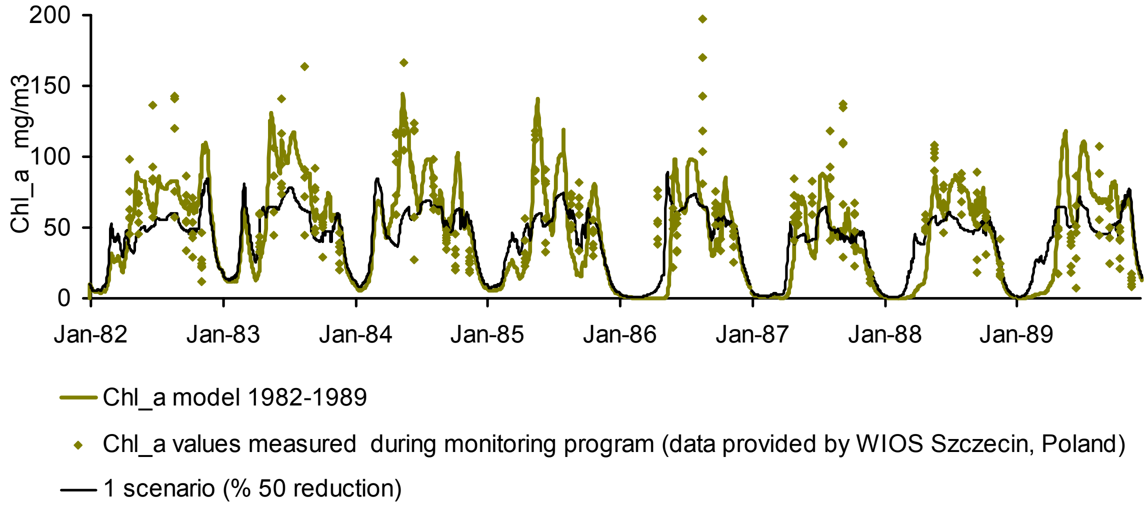

Figure 3 Results of the model simulations – Chl_a concentrations in the Szczecin Lagoon (Wielki Zalew).

The nutrient loads in 1990 as starting conditions for the second scenario after Behrendt et al. (2001) are already significantly lower compared to the first scenario (Fig. 2). The average chl_a reduction in the second scenario varies between 17 and 36 %. The results clearly show that these further nutrient load reductions reduce the phytoplankton biomass and the likelihood of intensive summer blooms.

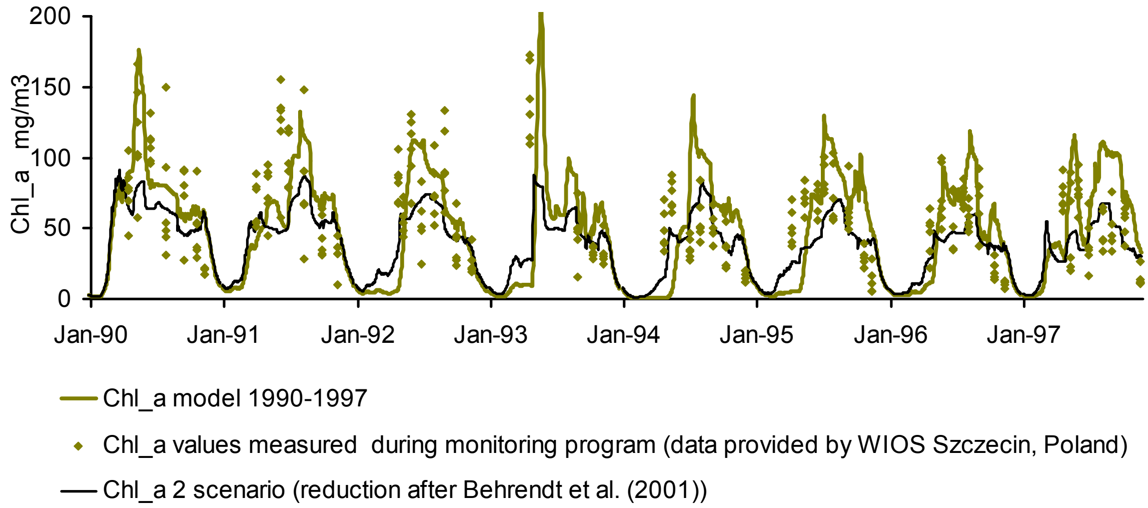

Figure 4 Results of the model simulations – Chl_a concentrations in the Szczecin Lagoon (Wielki Zalew).

A very important aspect in the second scenario is the different reduction of the nitrogen and the phosphorus load. The ratio between these two elements is shifted towards a higher relative availability of nitrogen. The model indicates that in the 80's and 90's the phytoplankton growth was controlled mainly by light availability, and by nutrient only during some limited periods. A phosphorus limitation was observed only during some years in spring and a nitrogen limitation during several summer months. The results of the reduction scenarios (Figures 3 and 4) indicate, that the nutrient load reduction suppresses the algal growth. In both cases the highest chlorophyll concentrations in late spring and summer were limited by the nutrient availability. The general pattern is the same like in the 80's and 90's, but the limitation periods are extended in time. The second scenario indicates that less phosphorus carried by the river (Figure 2) will reduce spring bloom of algae to a higher degree. However, at the same time the nutrient load reduction resulted in reduction of suspended matter load in the model. Thus due to lower light extinction winter and autumn favour higher algae growth and Chl_a concentration increased in colder season when the algal growth is not limited by nutrients.

4 Discussion

The results show that the model is generally suitable to serve as a tool in coastal water management. The simulations reflect only the situation in the eastern part of the lagoon (Wielki Zalew). On average, the Kleines Haff receives only about 20% of the Odra waters through the Wielki Zalew and water from a small catchment on German territory. In the separate simulations of the Kleines Haff it was assumed that most nutrient load reduction measures on the German side are already implemented and that a strong further reduction cannot be expected. It is likely that this simplification is one reason for the worse model performance in this part of the lagoon. In order to simulate nutrient reduction scenarios for the Kleines Haff, a detailed survey of emissions from its immediate drainage area is necessary. Due to the simple model structure uncertainties are connected to the results and a forecast for a complex and altering biological systems is always problematic.

The scenarios are a simplification. In the presented simulation the reduction rate was applied from the starting date, even though Behrendt *at al.,* (2001) suggested that these reduction targets can be met only within the next 10 to 20 years. So the expected reduction will not take place as soon as seen in the model simulation. But we assume that with a relatively simple box model it is possible to obtain some insight to the basic internal processes governing the phytoplankton growth such as factors controlling phytoplankton growth and observe changes of these factors following changing forcing functions of the model (e.g. external loads of nutrients). Such insight might be an indication of what management measures are needed.

However, the model gives some indication of the possible reaction of a water body system on management measures undertaken within its drainage area. The results indicate that the applied nutrient load reduction causes a certain reduction of phytoplankton growth. The external nutrient sources influence the phytoplankton growth (primary production) versus internal cycling can be seen by the model. Relatively low reduction of phytoplankton growth is a result of substantial nutrient recycling in a shallow well mixed water body. Despite the fact that estuaries and coastal regions contribute large portion of the “new” primary production (i.e. production based on nutrients originating from external sources) chemical and biological processes favour nutrient recycling too.

Of great practical importance is the suppression of the highest algal blooms during summer after nutrient load reductions. Summer blooms, especially of potentially toxic blue-green algae, occur at a time when the lagoon is intensively used for recreational purposes. Therefore, a reduction of summer algae bloom is most important for tourism industry. In this respect every nutrient load reduction is very useful.

After the German trophic classification system (Umweltministerium Mecklenburg-Vorpommern, 1998) the lagoon was mainly polytrophic during the 1980’s and showed a tendency to category 4 (strong eutrophic) during the 1990’s. According to the model, even the nutrient load reduction after Behrendt et al. (2001) will keep the lagoon in a eutrophic to strong eutrophic state. The results suggest that neither internal nor realistic external measures are able to shift the lagoon into a mesotrophic or even oligotrophic system. This might create problems for the implementation of the water framework directive.

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