Erweiterte Zusammenfassungen der Deutschen Gesellschaft für Limnologie (DGL/SIL); Jahrestagung 2001 in Kiel
Proceedings of the biannual conference of the German Society of Limnology in Kiel 2001

Baltic Sea Research Institute Warnemünde IOW

Spatial, seasonal and long-term changes of phosphorus concentrations in the Oder estuary

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Background

The large Oder river catchment is located at the German-Polish border. With a surface area of 120,000 km^2 and a population of about 13 Mio inhabitants it causes the heavy nitrogen and phosphorus load of the Oder river. In recently, about 63,000 t total N/a and 3,500 t total P/a were transported with the Oder towards the Baltic Sea. The river therefore is the most important source of eutrophication and pollution for the south-western Baltic Sea. The respective coastal zones, especially the Szczecin (Oder) Lagoon, suffer from severe eutrophication, heavy algal blooms of potentially toxic species, high water turbidity and hygienic water quality problems.
Goals of our work about the Szczecin Lagoon are the provision of processed information and models for water quality management and to support the regional implementation of the Water Framework Directive. For this purpose we analysed the spatial and temporal course of nutrient concentrations, carried out transport simulations and applied a simple eutrophication box model. Some results with respect to phosphorus are presented. The results are based on compiled data supplied by the Landesamt für Umwelt und Natur (LUNG), Güstrow, the StAUN Ueckermünde, and the Westpomeranian Inspectorate of Environmental Protection in Szczecin (WIOS).

Spatial gradients

The Szczecin Lagoon is a large (687 km^2) and shallow (average depth 3.8 m) coastal flow lake with a theoretical water exchange time of about 2 months. The lagoon consists of the Kleines Haff on the German side and the Wielki Zalew located on Polish territory. The Wielki Zalew is dominated by the influx of the Oder river, with an average annual discharge between 300 and 700 m^3/s. The P-load of the Oder causes pronounced spatial gradients which are, to a varying degree, modified by internal processes. The comparison between the periods 1980-91 and 1992-99 show lower concentrations and weaker gradients due to reduced P-load of the Oder river (Fig. 1).

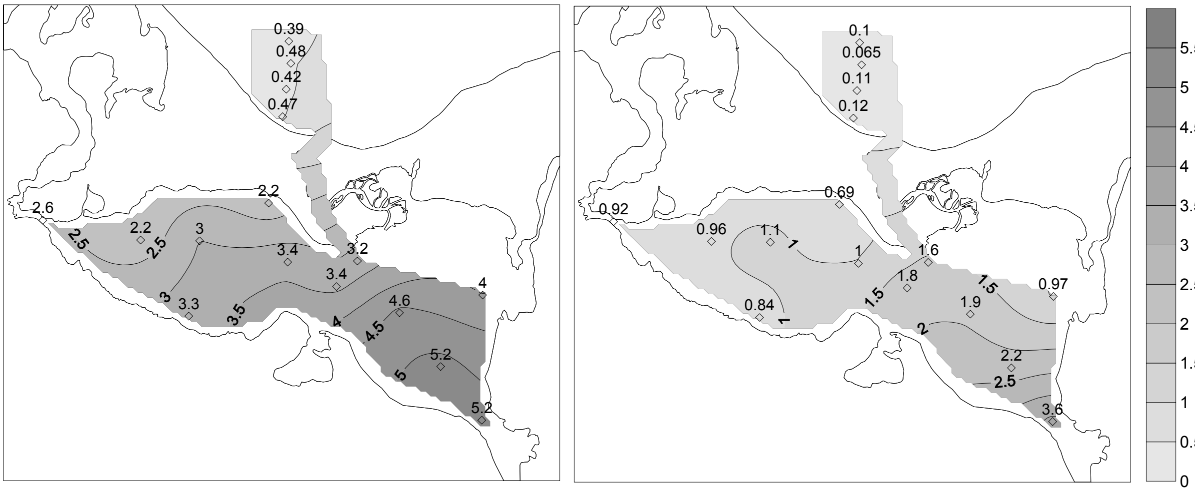

Figure 1: Median concentration of phosphate [µmol PO4-P/l] in June after the spring bloom of diatoms. Period 1980-91 (left) compared to 1992-99 (right). Data provided by LUNG (Güstrow), StAUN (Ueckermünde) and WIOS (Szczecin).

Long-term eutrophication

Phosphorus concentrations in the lagoon were already high in the 1980's. In the western part, the Kleines Haff, an increased concentration in early 90's is followed by a steady decrease (Fig.2). In wet years the P and N load in the Oder river can be up to twice as high compared to dry years. The pronounced reduction in nutrient loads in early 90's is an effect of the warm, dry years and cannot be attributed to anthropogenic nutrient load reductions (Schernewski & Wielgat 2001).

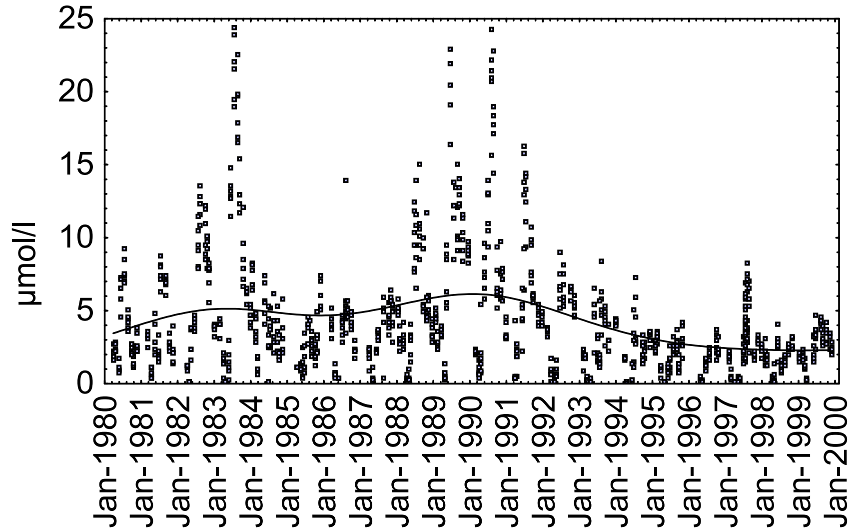

Figure 2: Time series of the phosphate concentration in the Kleines Haff (Data supplied by Landesamt für Umwelt und Natur (LUNG), Güstrow)

The Oder load controls the nutrient dynamic in the Szczecin Lagoon to a high degree, but the reduced load of the Oder river in early 90's is not reflected in the concentrations inside the lagoon (Kleines Haff) (Fig.2). It is very likely, that the decrease of concentrations in the Kleines Haff at the end of the century (Fig. 2) is already a result of improvements in sewage treatment around the lagoon and in the Oder catchment.

Annual dynamics

The annual course of phosphate concentrations (Fig. 3) show minimum values during spring and maximum values in the summer months. The spring minimum is a result of the diatom bloom, when phosphorus is taken up by algal. In some years a P-depletion is observed. High concentrations in summer clearly indicate that phosphorus is not a limiting nutrient during that time. Instead, nitrogen plays the most important role in summer. High phosphate concentrations in the inflowing Oder waters alone cannot explain the summer maximum. Fast mineralisation and, in some years, phosphorus release from anoxic sediments plays an important role, too. Due to internal processes, the quantitative changes in phosphate concentrations between the periods 1980-91 and 1992-99 are most pronounced in summer.

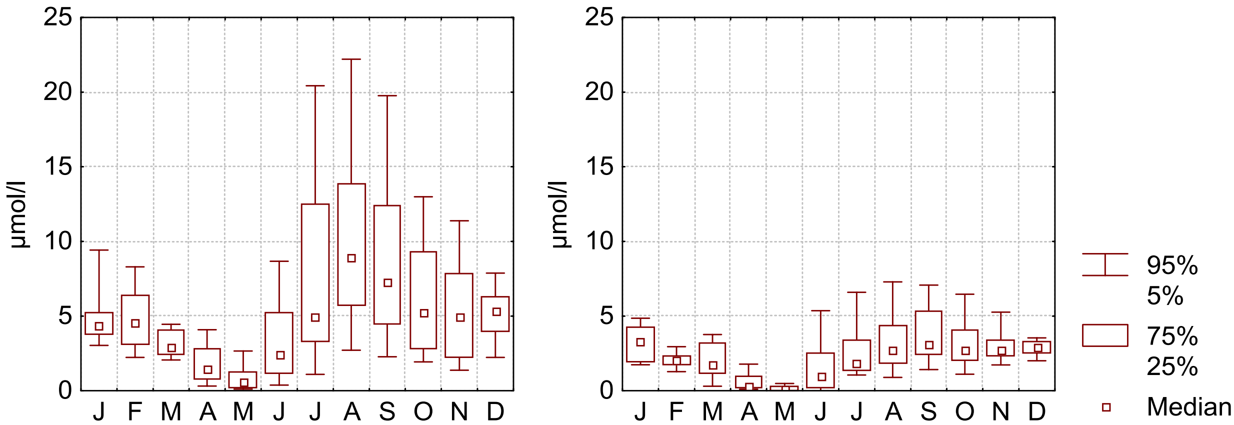

Figure 3: Annual variability of the phosphate concentration in the Kleines Haff

Modelling the Oder lagoon

The simple box-model at this stage consists of 7 state variables, namely: DIN, PO4, detritus (suspended organic matter) nitrogen and detritus phosphorus, nitrogen and phosphorus in the sediment as well as one phytoplankton group (Schernewski & Wielgat 2001). The phytoplankton state variable is expressed only in nitrogen units which can be converted to phosphorus using the Redfield N:P-ratio of 16:1. The model covers the dominant internal nutrient transformation processes in the estuary: nutrient uptake by phytoplankton, mineralisation, sedimentation, denitrification of nitrogen from water and sediment and loss to the atmosphere as well as burial of nutrients in sediment. The model is driven by external forces such as the seasonal changes of light and temperature, the nutrient loads discharged with the Oder river and from point sources in the immediate lagoon drainage area. In order to make long-term simulations possible, the internal time scale of the model is one day.

Figure 4 shows a comparison between monitoring-data (sub-surface measurements in central Wielki Zalew) and model simulations (solid lines). The model does not take into account temporary, local inflows of Baltic Sea water.

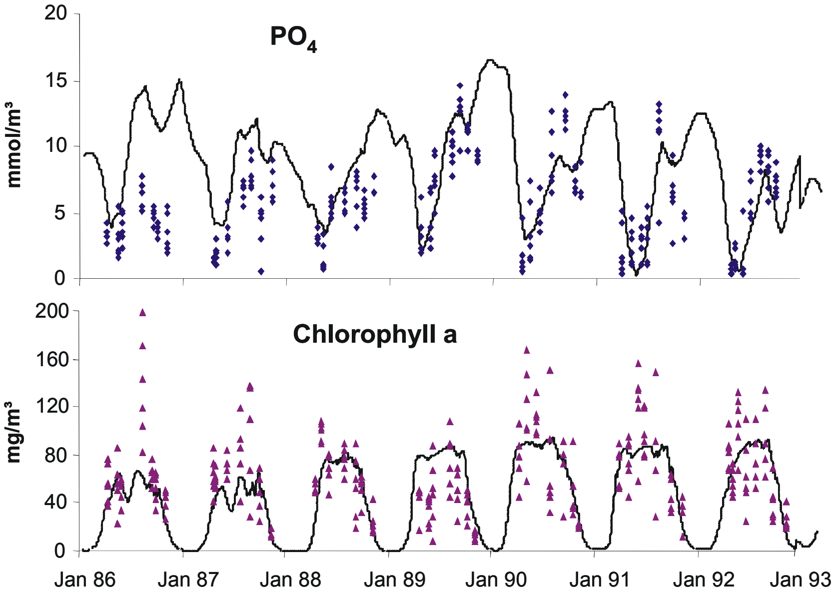

Figure 4: Comparison between model simulations (solid lines) and monitoring data supplied by the Westpomeranian Inspectorate of Environmental Protection Szczecin (points).

The long term model simulations of nutrient cycling in the lagoon will allow to get more insight into the processes taking place in the lagoon and espacially to quantify the magnitude of internal versus external processes. The first application shows, that the model results are well in agreement with measurements. A problematic aspect are the outstanding high P-concentrations in summer between 1989 and 1992. Neither the nutrient load nor mineralisation processes are able to explain these values. A process, which is not included in the model so far, obviously plays a role in these years.

Internal eutrophication: P-release from the sediments

In the warm years between 1989 and 1992 steep, short-term increases in dissolved phosphorus concentrations were found during June and August. Figure 5 shows the sub-surface concentrations of dissolved phosphorus at 6 locations in the Kleines Haff. The black bars indicate concentrations on 8.6.89, 11.7.90 and 18.6.91. The white bars indicate the increased values 4-5 weeks later (11.7.89, 16.8.90, 16.7.91). During rare and short calm summer periods a stratification and oxygen depletion above the sediment can take place in deeper parts of the shallow lagoon. Coarse calculations on the basis of model-simulations and data indicate an anoxic P-release from sediments of up to 10 µmol P $m^{-3}d^{-1}$. During short-term anoxic conditions in summer, up to 400-600 t P can be released from the sediments into the entire lagoon. These situations are restricted to several days and occur only in a few years. Wind with a daily average velocity above 2-3 m/s causes vertical water mixing and puts an end to anoxic P-release. Compared to a monthly summer load of 100-150 t P by the Oder river, this internal eutrophication in the lagoon is quantitatively important. It causes altered spatial gradients (Fig. 6) and an increased release of phosphorus into the Baltic Sea. Internal P-release from the sediments have no pronounced effect on biology, because P is not the limiting element for primary production during the summer months (Fig. 3). Internal eutrophication counteracts measures to reduce P-load and might become a problem for water quality management.

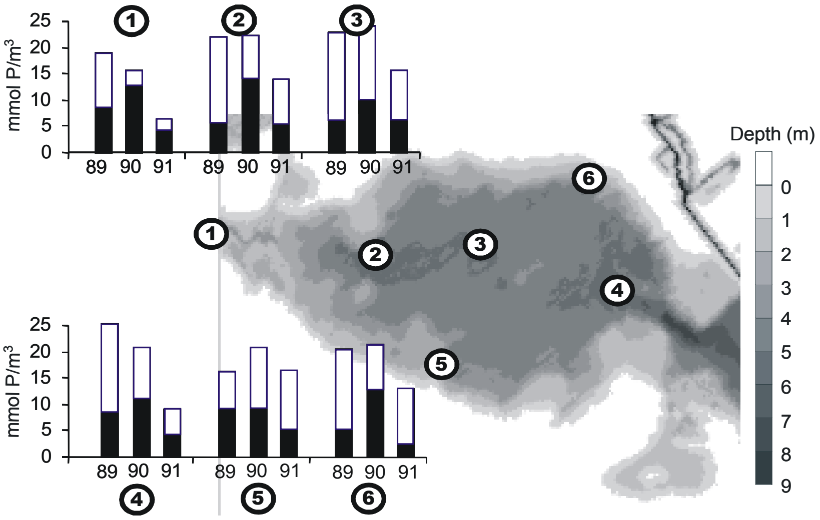

Figure 5: Increase of P-concentration due to P-release from the sediment in the years 1989 – 1991 (Schernewski & Wielgat 2001)

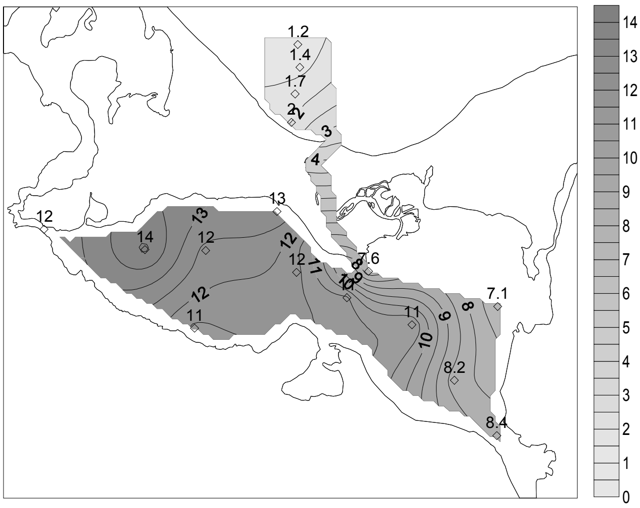

Figure 6: Median concentration of phosphate [µmol PO_4-P/l] in August influenced by anoxic P-release from the sediment in the Kleines Haff (1989 – 1991).

References

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