The trophic state of Germany's large rivers

L'état trophique des grands fleuves allemands

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RÉSUMÉ

Nous décrirons l'état trophique des 3 grands fleuves allemands Rhin, Moselle et Elbe pour la période allant de 2004 à 2008. Bien que ces fleuves aient des concentrations de nutriments de 0,19 – 0,27 mg/L de phosphore similaires, ils développent des masses de phytoplancton différentes. Ces concentrations de phytoplancton allaient de 5.8 µg/L chlorophyll-*a* dans le Rhin à 115 µg/L dans l'Elbe (valeurs moyennes saisonnières, mars-octobre), avec concentrations maximales de plus de 300 µg/L dans l'Elbe. Nous parlerons de ces différences et montrerons que d'autres facteurs que les concentrations de nutriments peuvent influencer la production primaire et les concentrations de phytoplancton dans les fleuves. Donc si nous voulons réduire de manière efficace le phytoplancton dans les fleuves, nous devons combiner différentes mesures qui comprennent non seulement la réduction des nutriments, mais également l'amélioration de la morphologie fluviale et de la structure de l'habitat.

ABSTRACT

Here, we describe the trophic state of three large rivers in Germany, Rhine, Moselle and Elbe, for the 2004-2008 five-year period. Although having comparable nutrient concentrations of 0.19 – 0.27 mg/L total phosphorus (seasonal means, March – October), these rivers developed highly different phytoplankton loads. Phytoplankton concentrations ranged from 5.8 µg/L chlorophyll-*a* in the Rhine to 115 µg/L in the Elbe (seasonal means, March-October), with maximum concentrations exceeding 300 µg/L in the Elbe. We will discuss these differences and show that other factors than nutrients can govern primary productivity and phytoplankton concentration in rivers. If phytoplankton loads are to be reduced effectively, a combination of measures should be taken into account, not only including nutrient reduction, but also improvements of river morphology and habitat structure.

KEYWORDS

Eutrophication, food-web, light, management, nutrients, water framework directive.

1 INTRODUCTION

Eutrophication is a major threat to aquatic ecosystems and has therefore been termed "one of the most important and long lasting water quality problems in the EU" by the EU commission. Although organic pollution and nutrient emissions into rivers in Germany has been strongly alleviated during the last two decades, eutrophication of rivers and coastal areas is still of great concern. In their actual state, phytoplankton is the dominant primary producer in large rivers. Inorganic nutrients, namely phosphorus, nitrogen and silica are prerequisites of primary production. Because of this direct link between phytoplankton and nutrient concentrations, the reduction of nutrient concentrations is the common means to improve the trophic state of rivers.

Here, we describe the trophic state of three large rivers in Germany, Rhine, Moselle and Elbe. Although having comparable nutrient concentrations, these rivers develop highly different phytoplankton concentrations. We discuss these differences and show that other factors than nutrients can govern primary productivity and phytoplankton concentration in rivers.

2 METHODS

Data examined here for the 5-year period 2004-2008 are from the Rhine at Koblenz (navigation-km 590, catchment area 110,000), the Moselle at Koblenz (navigation-km 6, catchment area 28,000 km^2) and the Elbe at Schnackenburg (navigation-km 475, catchment area 125,000 km^2). Samples for chlorophyll-*a* (Chla) and nutrients were taken at weekly (Moselle, Rhine) or biweekly (Elbe) intervals and were analyzed according to German Standard Methods. Light conditions were measured during Lagrangian sampling campaigns in the Elbe and the Rhine with a spherical sensor (LI-COR LI-193SA) that selects for photosynthetically active radiation (400-700 nm).

3 RESULTS AND DISCUSSION

Striking differences were found in the phytoplankton dynamics between the three rivers (fig. 1). Although carrying comparable total phosphorus concentrations, Chla concentrations differed by an order of magnitude. Phytoplankton concentrations in the lower reaches of the rivers were highest in the Elbe (seasonal mean from March – October 115 µg Chla/L, maximum 323 µg Chla/L). Phytoplankton concentrations in the Rhine only reached a maximum of 36 µg Chla/L (seasonal mean of 5.8 µg Chla/L). The Moselle, a tributary of the Rhine, had mean seasonal concentrations of 10 µg Chla/L with peaks in spring and reached a maximum of 106 µg Chla/L during the study period.

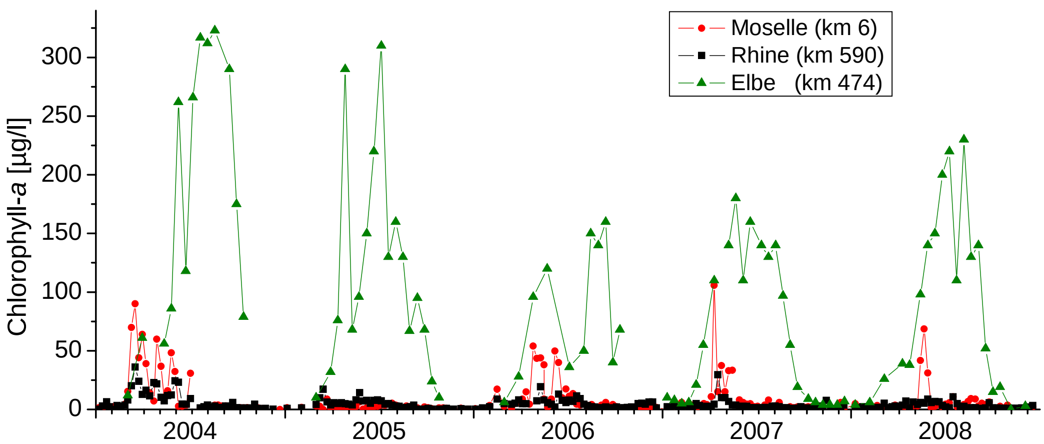

Fig. 1: Phytoplankton (chlorophyll-*a*) dynamics in lower reaches of the rivers Rhine, Moselle and Elbe for the years 2004-2008.

Nutrients: Total phosphorus during the season averaged 0.17, 0.19, and 0.27 mg/L in Elbe, Rhine and Moselle, respectively. Ortho-phosphate was 0.03, 0.13, and 0.12 mg/L. Low concentrations (below 0.01 mg/L) of ortho-phosphate and/or silica occurred regularly in the Elbe and sometimes in the Moselle, when phytoplankton concentrations were high.

Nutrient concentration is not the only and in most cases not the decisive factor that determines phytoplankton biomass in rivers (e.g. Reynolds & Descy 1996). The availability of nutrients is a necessary condition for phytoplankton growth that is met in most rivers with anthropogenic impact. However, the growth potential for phytoplankton biomass provided by nutrients is only reached in the Elbe where, during summer, ortho-phosphate and silica can exhibit concentrations low enough to limit nutrient uptake by algae. This external lack of nutrients does not necessarily mean that phytoplankton is really nutrient limited because of the algae's ability to grow from their internal nutrient storage pools. Rhine and Moselle rarely reached phytoplankton biomasses that depleted dissolved nutrients. Several other factors than nutrients determine the phytoplankton load at a certain position along the course of rivers.

Light conditions: Because the three rivers are fully mixed, water depth and turbidity determine the amount of light that the phytoplankton receives. In the relatively shallow Elbe, phytoplankton can contribute more than 50% to the total seston dry mass during summer. It grows to concentrations that limit light availability by self-shading. Thus, the depth at which growth can occur (usually expressed as the 1% light level) exceeded 2 m at navigation-km 4, but was only 0.9 m at navigation-km 503. This means that at relatively low water depths, the phytoplankton spends considerable time of the daily cycle under conditions that do not allow positive growth.

Initial phytoplankton concentrations: The Elbe includes in its upper catchment area a series of impoundments with good growth conditions for phytoplankton. Thus, when this river reaches the long, free-flowing section, there is already an initial biomass of 44 µg Chla/L (navigation-km 4, seasonal mean). In contrast, the Rhine has its major source for phytoplankton in large, pre-alpine lakes such as Lake Constance that supply only very low phytoplankton concentrations. This small inoculum needs more cell divisions to reach high biomasses and is easier to control by grazers.

Grazers: The Rhine and the Moselle inhabit high numbers of benthic filter feeders. While in the Moselle the Zebra Mussel *Dreissena polymorpha* dominates, high numbers of the Asian Clam *Corbicula fluminea* dwell in large sections of the Rhine. These filter feeders are able to control phytoplankton at least at certain times of the year (e.g. Schöl et al. 1999). In contrast, benthic filter feeders are rare in the free flowing stretch of the Elbe. Only in the lower course of the Elbe, zooplankton can grow to high abundances and may there be able to reduce the existing high phytoplankton biomass. Of course, other grazing organisms occur in all rivers. Particularly for the Rhine it has been shown that benthic and pelagic protozoa can play a major role in the food web (e.g. Bergfeld et al. 2009).

4 CONCLUSIONS

We demonstrate here that several factors can limit phytoplankton biomass in large rivers. While light availability seems to be a limiting factor in all rivers and is particularly important in the Elbe at high phytoplankton densities, phytoplankton biomass is controlled by several additional factors (flow time, grazing, initial concentrations) in the Rhine and the Moselle. Therefore, the realized trophic state of these rivers can be far below the trophic potential indicated by nutrient concentrations.

These complex relationships are not only of academic interest. Phytoplankton is one of the biological quality components for the water framework directive and is meant to indicate the pollution of rivers by nutrients. Sophisticated methods have been developed to assess the quality component phytoplankton. It may now happen that costly reductions of nutrients in the catchment do not improve "ecological status" as indicated by phytoplankton, because other factors like prolonged flow time in impoundments promote phytoplankton growth. Vice versa, rivers with high nutrient loads may be regarded as having the "good ecological status" because phytoplankton biomass is limited by fast runoff and deep water column (e.g. through channelisation) or by other factors mentioned above. While nutrient reduction can be regarded as a "no regret measure" and is of benefit for coastal regions, the latter case is difficult to communicate and could impede the necessary improvement of our rivers. If phytoplankton loads are to be reduced effectively, a combination of measures should be taken that do not only include nutrient reduction, but also improvements of river morphology and habitat structure.

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