

## ABSTRACT

The German Bight is characterised by high nutrient concentrations mainly due to N-rich discharges of the rivers Elbe and Weser. However, strong gradients and permanent tidal advection complicate quantification of biogeochemical processes. For this reason, mesocosm experiments, eliminating the frequent tidal shifts of gradients and tidal advection were carried out to study the development of phytoplankton community and nutrient cycling under seasonal physical and chemical conditions. In this paper, mainly nitrogen cycling in the enclosed pelagic ecosystem was studied based on the data analyses of the mesocosms. A box model was meanwhile developed and applied as complementary tool to quantify transformation of main N phases in the pelagic ecosystem within the low trophic level.

Two series of mesocosm experiments with natural (controls) and nutrient-enriched (experimental) plankton populations were carried out in Büsum in spring and summer, 1999. During both the spring and summer experiments, physical parameters (irradiance, temperature and turbidity), chemical parameters (nutrients, DOM, POM and DFAA) and biological parameters (primary production, chlorophyll *a* and phytoplankton species, bacteria) were frequently monitored, up to every two hours. Significant correlations of the parameters measured in the parallel bags reveal excellent reproducibility. The comparison of forcing parameters in the enclosures with those in the harbour surrounding and at offshore station indicates the representativity of the mesocosm experiments which were for the starting conditions given for the surrounding area, influenced by the spreading Elbe river plume.

The spring experiment was successful in tracing the start of a typical diatom spring bloom, dominated by *Thalassiosira* species with a long slow-growing phase prior to the exponential growth.

The light climate is the most essential factor to trigger phytoplankton spring bloom. In the enclosures, the compensation depth was lifted to the upper 2 – 3 m by keeping the planktonic community at the surface (2 to 3 m) of the turbid water. In the open water of the same turbidity, frequent vertical mixing which was including 20 m deep tidal channels, inhibited net primary production and prevented the formation of phytoplankton bloom in the adjacent area. Accordingly, both in spring and summer, no significant phytoplankton bloom was detected in the surrounding turbid inshore waters.

The development of phytoplankton growth within the mesocosms was controlled by the available nutrient concentrations. In spring, high DIN/DIP ratio in the water column indicated possible P limitation. P addition prolonged phytoplankton exponential growth and consequently caused an increase of the final phytoplankton standing stock. Nitrate, phosphate and silicate were taken up in relations close to Redfield ratios during the exponential growth phase.

In summer experiment, phytoplankton started exponential growth immediately after enclosure. The exponential growth phase lasted only for 3 days and was followed by a stationary and decay

phase caused by complete exhaustion of nutrients. Diatoms were succeeded by flagellates due to longer lasting Si regeneration. By daily addition of nutrients ( $\text{NO}_3^-$ ,  $\text{PO}_4^{3-}$  and Si) to some mesocosms phytoplankton was kept in exponential growth. In spite of deviating ratios from Redfield relations of added  $\text{NO}_3^-$ :  $\text{PO}_4^{3-}$ : Si, the ratios of particulate matter synthesis ( $\Delta\text{POC}:\Delta\text{PN}:\Delta\text{PP}$ ) were close to Redfield ratios.

Significant negative correlations of nutrients with chlorophyll *a* indicated the dominance of phytoplankton biomass synthesis in nutrient conversion both in spring and summer. The succession of  $\text{NH}_4^+$  and  $\text{NO}_3^-$  utilisation was observed during spring and summer when ammonium concentrations dropped below 3  $\mu\text{M}$ . Co-uptake occurred when  $\text{NH}_4^+$  was in the range of 1.0 to 3.0  $\mu\text{M}$ .  $\text{NO}_2^-$  release was observed during luxury  $\text{NO}_3^-$  uptake in both spring and summer, reaching about 1% of  $\text{NO}_3^-$  uptake.  $\text{NO}_2^-$  uptake followed  $\text{NO}_3^-$  depletion ( $< 1 \mu\text{M}$ ). Results from model runs show during spring exponential growth phase nitrate uptake of 8 – 10  $\mu\text{M}/\text{d}$  which were in the same order for control and nutrient enriched systems. During summer only 2  $\mu\text{M}/\text{d}$  nitrate were utilised but 5  $\mu\text{M}/\text{d}$  ammonium, reaching in total the same range as during spring. Following addition of nitrate, its uptake rate increased to 13 – 14  $\mu\text{M}/\text{d}$ .

In the enclosures, DON remained at steady state concentrations around 20  $\mu\text{M}$ , controlled by the processes of production and losses by bacteria utilisation during most of the experiments. During spring, a slight increase of DON was related to phytoplankton cell release during the exponential growth phase. During summer, DON increases were mostly attributed to the detritus decomposition related to bacterial activity. Modelled fluxes generating the fraction of dissolved organic nitrogen were in spring calculated between 0.06 and 0.22  $\mu\text{M}/\text{d}$ , balanced by decomposition rates of 0.14 – 0.18  $\mu\text{M}/\text{d}$ . These fluxes were during summer significantly increased: 0.96 – 2.49  $\mu\text{M}/\text{d}$  increase and 0.69 – 0.9  $\mu\text{M}/\text{d}$  decomposition, indicating the temperature effect on bacterial turnover.

Mass balances of nitrogen revealed significant N loss during both spring and summer experiments, which were attributed to denitrification by particle-attached bacteria. Calculated denitrification rates were 1.5  $\text{mmol m}^{-2} \text{d}^{-1}$  in spring and 2.5  $\text{mmol m}^{-2} \text{d}^{-1}$  in summer.

By frequent sampling, diurnal changes of phytoplankton turnover such as nitrate uptake and nitrite release could be followed. Phytoplankton photosynthesis rates were higher in later morning of 5 to 8  $\mu\text{g POC} (\mu\text{g chl}a)^{-1} \text{h}^{-1}$  and showed a decrease during nights and reached to the low rates of  $-1$  to  $-2 \mu\text{g POC} (\mu\text{g chl}a)^{-1} \text{h}^{-1}$ . Diurnal  $\text{NO}_3^-$  uptake estimated from spring varied from 0.001 to 0.025  $\mu\text{M} (\mu\text{g chl}a)^{-1} \text{h}^{-1}$  at night and 0.004 to 0.052  $\mu\text{M} (\mu\text{g chl}a)^{-1} \text{h}^{-1}$  at daytime.

A box model mainly focusing on nitrogen cycling in the pelagic system was applied to study the biogeochemical conversion of the main phases of nitrogen within the lower trophic level, including two groups of phytoplankton (diatoms and flagellates), herbivorous zooplankton, nutrients (nitrate, nitrite, ammonium, phosphate and silicate), dissolved organic matter (DON, DOP) and detritus. It was driven by the forcing variables of irradiance and temperature. After

calibrated with the measurements in the spring control system, the model was validated with data from the summer control system. It was then applied to ‘hindcast’ the development of the spring and summer experimental systems with nutrient enrichments with the purpose of verification.

Comparing the simulations with the measurements, the model simulated successfully the development of the main N compartments in control bags in spring and summer, and was able to simulate the experimental systems as well. Based on the good consistency between the simulations and measurements, N fluxes of the main processes were calculated. Phytoplankton biomass formation was the dominant process both in spring and summer, accounting for 75% and 60% of DIN uptake, respectively. 5% of DIN utilised in spring and 22% in summer were remineralised to ammonium which was taken up again by the phytoplankton nearly completely.

Limitations of the model were given by the ability of phytoplankton cells to store P and modifications of nutrient utilisation due to the different nutrient status within the cells, which could not be considered by the applied Michaelis-Menten-Monod equation. This resulted in unsatisfactory simulations of  $\text{PO}_4^{3-}$  and Si uptake during the period of nutrient addition in the summer experimental bags. In the current model, bacteria were only implicitly included in degradation, nitrification and denitrification, causing higher deviations between model results and measurements during summer due to higher bacterial activity compared to spring.

The combination of mesocosm experiments with the box model allowed a detailed analysis of the biogeochemical fluxes within the dynamic nutrient-rich coastal waters, as shown by nitrogen compounds. The knowledge of the reaction potential of river plume water is of importance for future management measures.