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Towards a natural Wadden Sea?

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Abstract

Since 1990 the input of phosphorus into Dutch coastal waters and the Wadden Sea has been strongly reduced but, primary production in these waters stayed high. Shortly after 2000, however, the years with a persistently high primary production under low P-discharge of the Rhine seem to have come to an end. In order to investigate whether nutrient shortage is the reason for the present small spring bloom magnitude and duration, bacterial bioassays were conducted in the winter and early spring of 2003 and 2004. We used weekly high tide samples from the Marsdiep Station to determine the natural abundances of bacteria and algae (diatoms and *Phaeocystis globosa*) and, to measure the effect of additions of C, P and N on bacterial growth-rate. In both years, only *Phaeocystis* showed a spring bloom at the end of March, which was accompanied by an outburst of bacterioplankton. The bioassays showed that, until the start of the *Phaeocystis* bloom, bacteria were carbon limited. During the exponential phase of the bloom, the bacteria were not limited by carbon nor by nutrients. In both years the *Phaeocystis* bloom stopped already in April. At the same time the bacterial bioassay pointed to severe P-limitation. In the Marsdiep, the PO_4-concentration dropped to only 0.048 μM and we conclude that the early termination of the spring bloom of *Phaeocystis* was due to P-depletion. Possible reasons why it took more than 10 yr before the spring phytoplankton bloom in Dutch coastal waters showed any response to the reduction in the P-discharge of the Rhine and possible consequences for the Management of the Wadden Sea are discussed.

Keywords: Eutrophication; *Phaeocystis*; Bacterial bioassay; Nutrient limitation; Wadden Sea

1. Introduction

The Wadden Sea (Fig. 1), with more than 3000 km2 of intertidal area Europe's largest estuary, has been studied for more than a century now, leading to a wide variety of scientific publications including many on tidal mudflat ecology (see e.g. the references in Colijn and van Beusekom, 2005). During low tide, the tidal mudflats are important feeding grounds for migratory water birds and, during high tide, for shrimps, crabs and juvenile stages of several North Sea fishes. The subtidal of the Wadden Sea is a productive area for the shrimp fishery and mussel culture. The total biomass annually removed by migrating predator populations, as well as the annual commercial harvest, are basically export production, which could impossibly be generated each year if the Wadden Sea were a closed recycling system. Instead, the productivity of the Wadden Sea is based on a substantial and structural input of dissolved nutrients and particulate organic matter from the North Sea and Lake IJssel (Postma, 1978; Cadee, 1980; Kuipers et al., 1981; De Wilde & Beukema, 1984; van der Veer et al., 1989; de Jonge, 1990). This makes the Wadden Sea in

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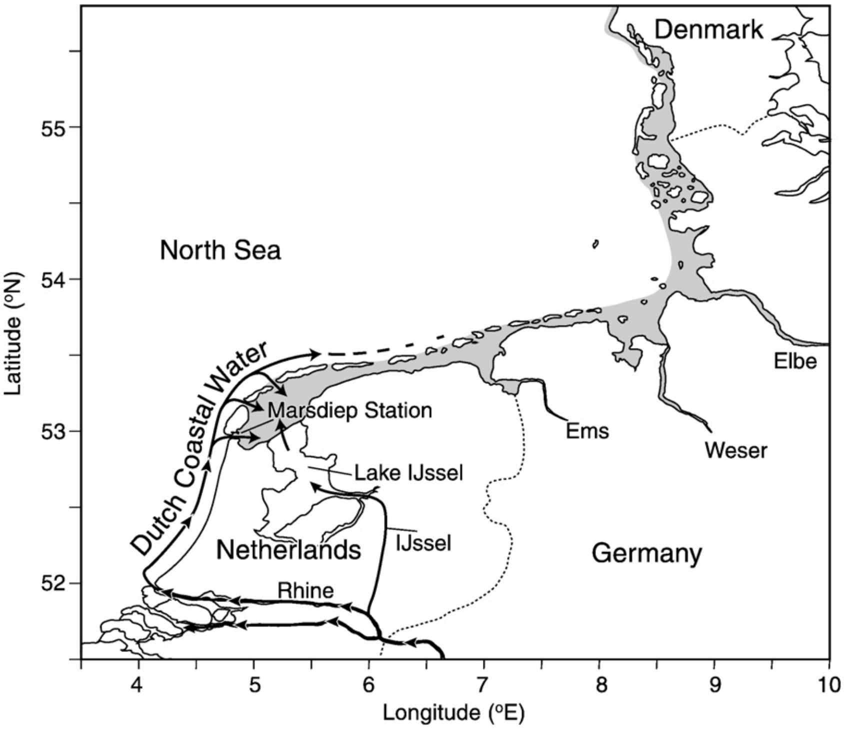

Fig. 1. Map of the international Wadden Sea (hatched area) with arrows indicating the current of Dutch Coastal Water transporting the discharge of the Rhine to the tidal entrances of the Wadden Sea and, the river IJssel discharging in Lake IJssel which connects with sluices to the westernmost Wadden Sea compartment.

principle a sub-system of a much wider ecosystem: a compartment where productivity depends on input factors with which the internal estuarine processes have no feed-back relationship.

The main source of nutrients for the Dutch Wadden Sea has long been known to be the Rhine and its relatively small branch river IJssel (appr. 1/4 of the whole), which flows through Lake IJssel to the western Wadden Sea. The Rhine itself discharges near Hoek van Holland into the North Sea where it contributes to the formation of Dutch coastal water, the ca 20 km wide water mass flowing along the continental coast of the Netherlands to the North-East. Although strong south-westerly to north-westerly winds prevailing in this area can change the picture drastically, the nutrient discharge of the Rhine reaches the tidal entrances of the western Wadden Sea on average in about a month. (Postma, 1954; Talbot, 1978). From there, the different tidal basins of the estuary are filled twice daily with in total several km^3 of Dutch coastal water. In spring and early summer heavy phytoplankton blooms develop in the current of coastal water before it enters the Wadden Sea (Gieskes and Kraay, 1975). Once in the estuary, the imported bloom material adds substantially to the food consumed and mineralized by the Wadden Sea's extensive populations of estuarine bivalves, crustaceans and polychaetes and, by the anaerobic bacteria in the mudflat sediment (Kuipers et al., 1981; de Wilde and Beukema, 1984; Vosjan, 1987; Cadée and Hegeman, 2002). The discharge of Lake IJssel, containing nutrients, particulate organic matter, freshwater plankton and sometimes even small fish, is sluiced at rather irregular times directly into the back of the westernmost Wadden Sea compartment, where it mixes with the entering coastal water (De Jonge, 1990; van Raaphorst and de Jonge, 2004).

The nutrient discharge of the Rhine has undergone large changes in the second half of the 19th century, as extensively reported in the literature (see e.g. the review of Colijn and van Beusekom, 2005; Cadée and Hegeman, 1993, 2002). From 1950 onwards, due to the post-war economic development of western Europe, the concentration of dissolved organic and inorganic nitrogen increased steadily everywhere in fresh water and rivers. Besides, due the widespread use of detergents containing phosphate in the 1960s, the phosphorus discharge of the Rhine increased to a historic maximum in 1980 (Fig. 2). These trends were also observed in the