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Phytoplankton composition in Dutch coastal waters responds to changes in riverine nutrient loads

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ABSTRACT

The Southern Bight of the North Sea is a shallow shelf sea, strongly influenced by river-borne nutrient loads. Eutrophication symptoms manifest themselves as high levels of chlorophyll-a and long-lasting, extensive blooms of *Phaeocystis globosa*, especially in the waters along the continental coast. As a consequence of measures to reduce eutrophication, riverine phosphorus loads have decreased more than 50% in the last two decades, and nitrogen loads show a decrease of ca 30%. While decreases in riverine N and P loads are observed, an increase in summer river-borne loads of silica occurred.

Since 1990, The Netherlands has carried out a routine monitoring program in the North Sea, including analysis of phytoplankton composition and carbon biomass. An analysis of these data for the period 1990–2007 shows a trend in phytoplankton composition, toward an increase in diatom biomass, increased bloom frequency and maximum bloom cell numbers of several diatom species, in particular *Chaetoceros socialis*, in the coastal waters. These changes coincide with increases in riverine Si loadings and increased Si concentrations in coastal waters as a consequence of changed river loads.

1. Introduction

The Southern Bight of the North Sea is a shallow shelf sea that is strongly influenced by Channel water and by riverine discharges. In particular the south-eastern coastal waters of the North Sea, along the continental coast from Belgium to Denmark, can be considered a Region of Freshwater Influence (ROFI). A number of continental rivers (Scheldt, Meuse, Rhine, Ems, Weser, Elbe), draining watersheds with a total surface of ca 430,000 km^2 and a total population of ca 81 million inhabitants (Tockner et al., 2009; Wollast 2003), discharge into the southern North Sea. The nutrient loads from these rivers are a major source of nutrients and fuel phytoplankton blooms in these coastal waters (De Vries et al., 1998; McQuatters-Gollop et al., 2009). Dutch coastal waters are predominantly affected by the rivers Scheldt, Meuse and Rhine. Of these three rivers, the river Rhine contributes by far the largest fraction (>70%). Changes in riverine nutrient loads, as a consequence of increases in nutrient concentrations in the freshwater systems after 1970 (Billen et al., 2005; Colijn et al., 2002; De Vries et al., 1998; Soetaert et al., 2006) and decreases due to measures to reduce eutrophication in the last two decades, can be expected to be reflected in the nutrient concentrations in Dutch coastal waters. Indeed, it was shown by De Vries et al. (1998) that there is a strong relation between riverine nutrient loads and nutrient concentrations in Dutch coastal waters of the North Sea.

Phosphorus concentrations have decreased in many European rivers since the early 1990's, and this reduction is also apparent in coastal waters, whereas the reduction in nitrogen concentrations in freshwater systems and coastal waters is much smaller (Ærtjeberg et al., 2001; Clausen et al., 2009; Lenhart et al., 2010; McQuatters-Gollop et al., 2007). It is generally assumed that the elevated levels of N and P in coastal waters not only resulted in elevated levels of phytoplankton biomass, but may also have caused shifts in phytoplankton composition. The surplus of nitrogen relative to silicon is assumed to have led to increased silicon-limitation of diatoms and a competitive advantage for non-silicon using phytoplankton species (Egge and Aksnes, 1992; Officer and Ryther, 1980). The high levels of blooms of *Phaeocystis globosa* in the southern North Sea, for example, have been associated with the surplus of nitrogen left at the end of the diatom spring bloom, and the capacity of this species to compete under low phosphorus concentrations (Gypens et al., 2007).

It has been proposed that eutrophication in the freshwater systems and the associated elevated levels of phytoplankton blooms also affect silicon retention in the freshwater ecosystems, and may lead to decreased silicon loads to coastal waters. Thus, freshwater eutrophication may not only have caused increased N and P loads to coastal waters, but also decreased Si loads, enhancing the effect of increased riverine N and P loads on changes in coastal phytoplankton composition (Admiraal et al., 1990).

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Decreases in N and P loads occurring during the last decades, as a consequence of measures to reduce eutrophication, could be expected to reverse the system to conditions favoring diatom growth.

Along the Dutch coast the freshwater influence extends in a relatively narrow band of up to 20–50 km wide (Baretta-Bekker et al., 2009; De Vries et al., 1998). This coastal area and the offshore waters in the Dutch part of the North Sea are part of an extensive Dutch monitoring program. In this program detailed information on phytoplankton community composition is obtained by quantitative microscopical analysis. In a first analysis of these data distinguishing four functional groups of phytoplankton (diatoms, auto- and mixotrophic dinoflagellates, *P. globosa* and other flagellates), Baretta-Bekker et al. (2009) showed that the overall picture was an increase in diatom and dinoflagellate biomass over the period 1990–2005. The authors did not try to identify the factors causing these changes.

Here we present the results of a more elaborate analysis of the trends in phytoplankton composition during the period 1990–2007, at eight monitoring stations in Dutch coastal waters near the discharge points of the main rivers and at two offshore stations in the southern North Sea. At the coastal stations effects of changes in riverine nutrient loads can be expected to have the strongest effects on phytoplankton biomass and composition. To study the changes in phytoplankton composition and biomass, we distinguished the same phytoplankton groups as in the earlier analysis by Baretta-Bekker et al. (2009), viz. diatoms, dinoflagellates, *P. globosa* and other flagellates. In addition to having a data series for a longer period, changes in phytoplankton abundance and biomass were studied in more detail by looking at the development of a selection of bloom-forming species. Changes in riverine discharges were analyzed to study the relationships between changes in phytoplankton abundance and composition and potentially causal factors like nutrient loads.

2. Material and methods

2.1. Sampling stations

The North Sea sampling stations that were selected for this analysis are shown in Fig. 1. These stations form part of the extensive Dutch national monitoring program (www.waterbase.nl). The sampling stations comprise three transects perpendicular to the coast.

The Walcheren transect is located in the southwest of The Netherlands, near the mouth of the Westerschelde estuary (the outflow of the river Scheldt), and has three stations at 2, 20 and 70 km distance from the coast (indicated as W02, W20 and W70, respectively). The station G06 is situated at 6 km off the coast in the southwest, near the mouth of the Haringvliet where a mixture of water from the rivers Meuse and Rhine is discharged. The stations were sampled at regular intervals with a monthly frequency.

The Noordwijk transect is located on the central western coast of The Netherlands, north of the discharge points Haringvliet and Maassluis which are the outflows of the rivers Rhine and Meuse. The transect has four stations at 2, 10, 20 and 70 km off the coast (indicated as N02, N10, N20 and N70, respectively). The Terschelling transect is located in the northwest of The Netherlands. Two stations, at 4 and 10 km off the coast of the barrier islands of the Wadden Sea, were included in this analysis (indicated as T04 and T10, respectively). The stations at the Noordwijk and Terschelling transect were sampled at least bi-weekly. Stations at the Terschelling transect further offshore, with summer

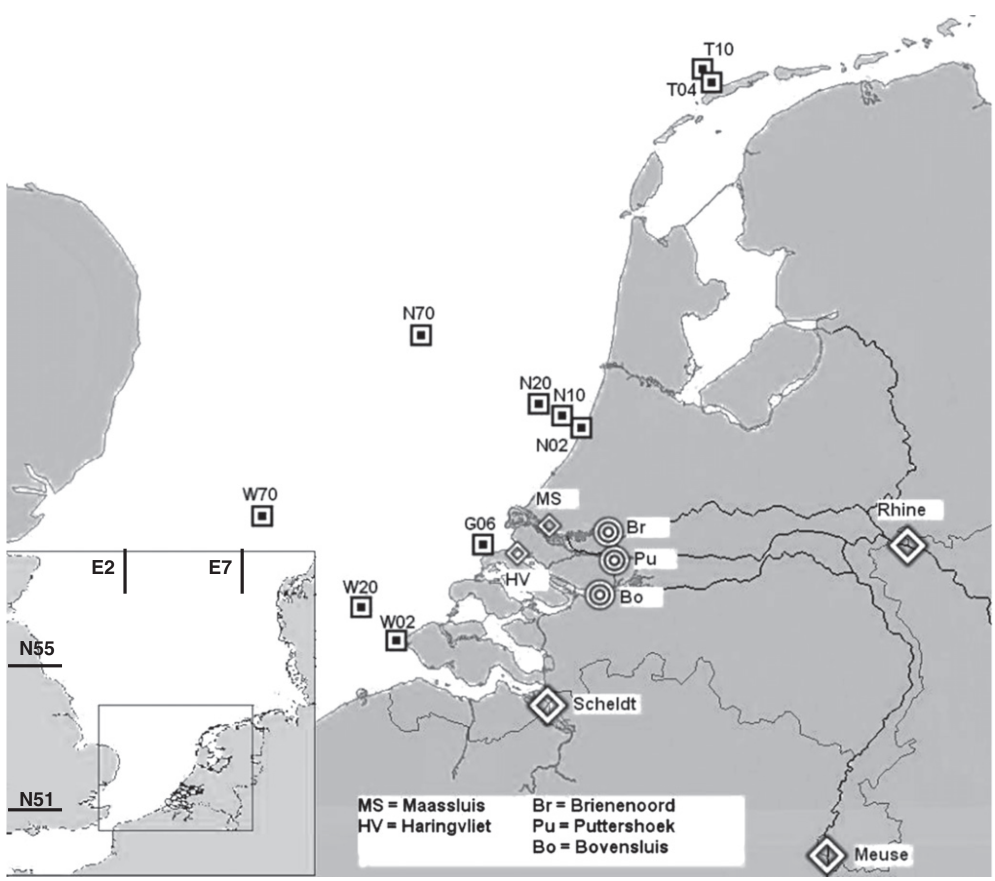

Fig. 1. Map of the research area showing the sampling stations in the North Sea (squares), the main river discharge points (diamonds), the sampling stations in the tributaries of Rhine and Meuse (circles), in the Rhine at the Dutch/German border and in the Meuse at the Dutch/Belgian border (diamonds).