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ORIGINAL ARTICLE

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Effects of the severe winter 1995/96 on the biological oceanography of the Sylt-Rømø tidal basin

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Abstract Water temperature, salinity and precipitation, micronutrients (N, P, Si) and chlorophyll *a* concentrations in the Sylt-Rømø tidal basin (German Bight) deviated between the early 1990s, with mild winters, and the years 1996–1997 with a severe winter and a moderate winter. As a consequence of low temperature, offshore winds and low precipitation in the severe winter 1995/96, salinity peaked in February 1996 and nitrate concentrations were low. The latter further decreased in March as chlorophyll *a* peaked with an exceptional bloom of the diatom *Odontella aurita*, probably triggered by low water temperature. Winter temperatures and spring chlorophyll *a* in the Sylt-Rømø tidal basin correlate well with the climatic North Atlantic Oscillation index.

Keywords NAO · Wadden Sea · Micronutrients · Chlorophyll · Variability

Introduction

The Sylt-Rømø basin is a part of the northern Wadden Sea (German Bight), situated between the barrier islands of Sylt (Germany) and Rømø (Denmark), and the mainland. Artificial dams in the north and south separate the bight from the adjoining Wadden Sea. There is only a single connection with the North Sea, a relatively narrow tidal inlet called Lister Deep. The basin is relatively shallow, with about 33% intertidal flats. Deep channels (below NN –5 m) comprise only 10% of the basin. Therefore air temperature and rainfall markedly affect the oceanography of the bight and a clear signal in chemistry and biology should be found as a consequence of a severe winter such as that of 1995/96.

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Methods

Weekly measurements on the biological oceanography of the Sylt-Rømø tidal basin have been performed since 1975, including the parameters water temperature (reversing thermometer), salinity (Autosal 8400a salinometer), the micronutrients PO_4, NH_4, NO_2, NO_3 and Si (after Grasshoff 1976), and chlorophyll *a* (UNESCO standard method). Additional meteorological data (e.g. daily rainfall, daily wind direction and wind velocity) were obtained from the Wetterstation List of the Deutscher Wetterdienst.

Water samples for the chemical analyses were collected by TPN water samplers close to the surface of a major tidal inlet. Strong turbulence prevents a thermohaline stratification in these waters (Hickel 1980; P. Martens, unpublished data). Therefore, samples from the water surface are regarded as representative of the entire water column. Measurements from the Sylt-Rømø tidal basin were compared to the North Atlantic Oscillation Index (NAO) as provided by Salmon (1998).

Results

Water temperature

The seasonal cycle of water temperature in the Sylt-Rømø tidal basin is nearly sine-curved. Between 1991 and 1995 the lowest monthly mean was about 2°C while summer temperatures rose to 21°C (Fig. 1). The severe winter of 1995/96 was mirrored in a water temperature 4–5°C lower than during the preceding (1991–1995) period and it took until May to reach the level of previous years (Fig. 1). In January 1997 the water temperature was as low as the year before but then showed a steep increase to values 3°C higher than during the early 1990s in August (Fig. 1).

Salinity and precipitation

The lowest salinity usually occurs in February/March, about 1 month after the high precipitation at the begin-

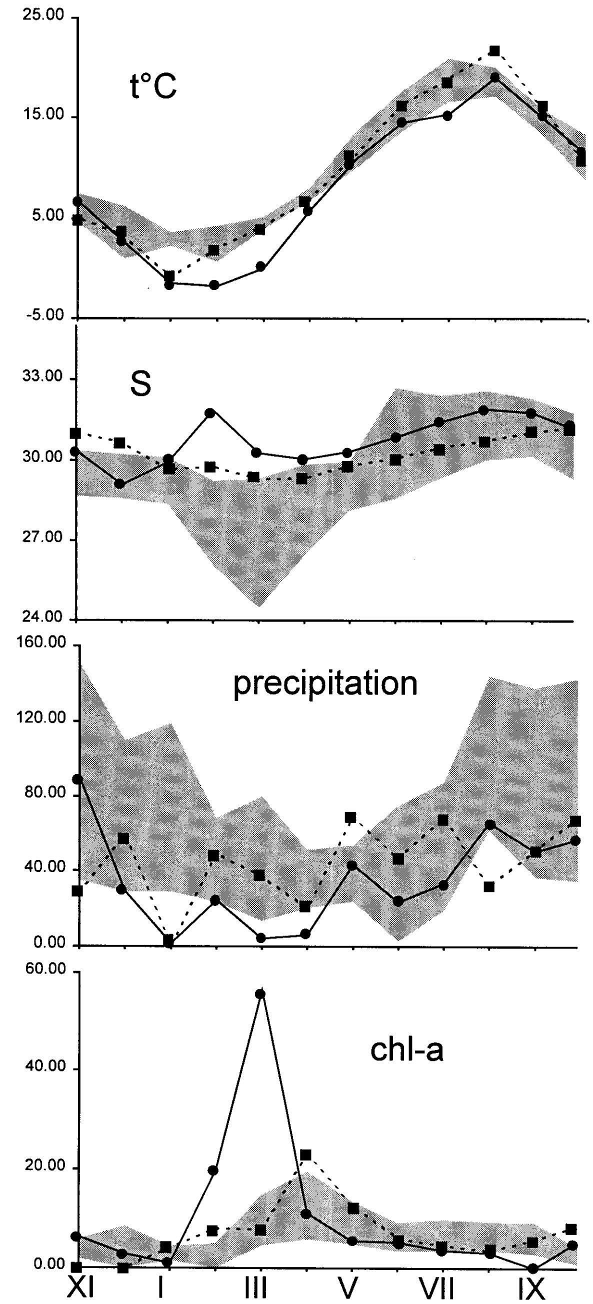

Fig. 1 Mean monthly values of water temperature (°C), salinity (PSU), chlorophyll *a* (µg l^{-1}) and precipitation (mm m^{-2}), in the Sylt-Rømø tidal basin in 1996 (●—●) and 1997 (■---■), *grey area* range in 1991–1995

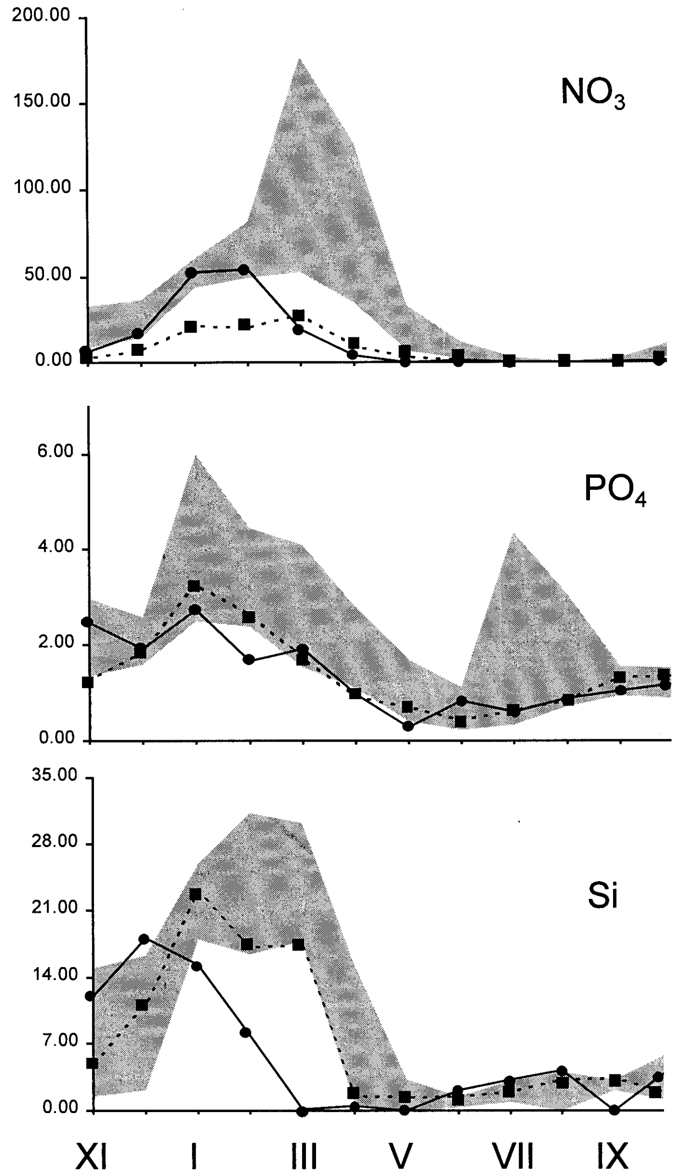

Fig. 2 Mean monthly values of nitrate, PO_4 and Si (µmol dm^{-3}) in the Sylt-Rømø tidal basin in 1996 (●—●) and 1997 (■---■), *grey area* range in 1991–1995

ning of the year (period 1991–1995; Fig. 1). The annual maximum salinity measurement is typically found in August/September, coinciding with the annual maximum water temperature and evaporation. In October/November, salinity decreases, again with a time lag relative to the high rainfalls in late summer (Fig. 1). In 1996 salinity did not show the usual spring decline. Instead, there was a steep increase in February, reaching values as high as in a typical August. Unlike the previous years, precipitation in January was close to zero (Fig. 1). The same occurred in January 1997, but in February precipitation rose to values similar to those in the preceding years (Fig. 1). As a result, the seasonal trend in salinity resembled a very smoothed curve, with no spring decline as in previous years, and no marked increase as in 1996.

Micronutrients and chlorophyll concentration

The amounts of micronutrients present usually attain maximum values in the end of winter (Fig. 2). Afterwards nitrate concentrations sharply decrease from March onwards and attain a summer minimum in August. This decline coincides with increasing chlorophyll *a* concentrations (Fig. 1), with maximum values in

April/May. Silicate (Fig. 2) shows a similar seasonal trend but minimum values occur earlier than for nitrate. Phosphate concentrations tend to decrease moderately during spring, with concentrations always well above the limit of detection. There is no significant correlation with chlorophyll.

In 1996 the spring micronutrient concentrations differed markedly from the previous period. In January, nitrate concentrations were the same as in the previous years, but then the usual late winter increase did not occur. Instead there was a decline in February/March and minimum values occurred as early as May. This coincided with an early rise of chlorophyll concentration in February/March (Fig. 2). The same tendency occurred with silicate, which was below the level of detection as early as March. Phosphate concentrations were lower than during the previous years but had a similar seasonal trend as in the 1991–1995 period (Fig. 2).

The 1997 nitrate level was very low during the entire year (Fig. 2) while phosphate and silicate concentrations did not differ markedly from the mean values of the 1991–1995 period. Chlorophyll *a* attained maximum values in April, with levels markedly lower than in 1996. The 1997 phytoplankton spring bloom started about 1 month later than in 1996 (Fig. 1).

Discussion

After the severe winter of 1995/96 the seasonal trends as well as the absolute values of the parameters investigated differed markedly from the preceding years. The March decrease in salinity usually follows the heavy rainfalls in January and February with a 1 month time lag (see the years 1992 and 1994 in Fig. 1). This is the time needed by the River Elbe water to reach the Sylt-Rømø tidal basin (Hickel 1980). Nitrate increases simultaneously with the salinity decrease. This is due to the high nitrate load (about 160 µg dm^{-3}) in the Elbe water (Martens 1989). Neither an increase in nitrate concentration nor a decrease in salinity occurred in 1996. Instead there was a sharp increase in salinity in February.

In the winter of 1995/96 strong offshore winds prevailed (Fig. 3) and apparently deflected the River Elbe plume from the coast. As a consequence only a little riverine water of low salinity and high nitrate concentrations entered the Sylt-Rømø tidal basin. The intermittent salinity peak in February may be the result of an intensive ice formation at temperatures below –2°C, increasing salinity in the residual water.

These low temperatures together with almost zero precipitation at the beginning of the year 1996 resulted also in a decreased input of the River Elbe into the German Bight, as can be seen from relatively low nitrate concentrations near Helgoland (about 30 µg dm^{-3}) (P. Mangelsdorf, unpublished data). Accordingly, the nitrate peak usually observed in March was missing. Instead there was a sharp decline starting in February and coinciding with a strong phytoplankton bloom. This was in effect a monospecies bloom formed by the meroplanktonic diatom *Odontella aurita* (Lyngb.) Agardh (G. Drebes, unpublished data). Its transition into the planktonic stage is primarily triggered by low temperature (Cleve-Euler 1951; Baars 1986). Silicate decreased in parallel with nitrate and the formation of this phytoplankton bloom.

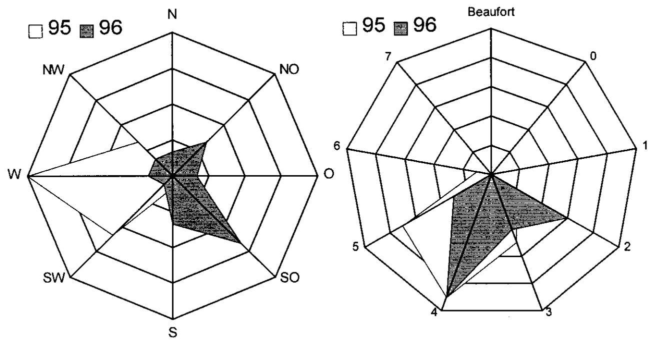

Fig. 3 Wind direct/on *(left)* and windforce (*right*, in Beaufort) in February 1995 and 1996 in the Sylt-Rømø tidal basin

The year 1997 demonstrates the strong interannual variability of this region. As in 1996 there was no decrease in salinity in March, due to low precipitation (Fig. 1) and low temperatures in January (Fig. 1). However, temperature increased sharply in February, reaching the mean values of the early 1990s. No *Odontella* bloom, as seen in 1996, occurred and the micronutrients reached their minimum values later than in 1996. Nitrate values in spring were low compared with earlier years. During the same time period, nitrate concentrations near Helgoland reached 70 µg dm^{-3}, twice as much as in 1996 (P. Mangelsdorf, unpublished data). This phenomenon can not be explained by the local wind measurements. The mean wind direction was south-west. One possible explanation could have been “the stormy easterly winds in the southern German Bight at the beginning of 1997, which led to a surface current in westward direction” (Weigelt 1997) and shifted the River Elbe plume from the coast in an westerly direction (Helgoland).

Early in the twentieth century, meteorologists noticed that year-to-year fluctuations in winter air temperatures on both sides of Iceland were often out of phase with one another. When temperatures were below average over Greenland they were above average in Scandinavia, and vice versa. Simultaneously, coherent fluctuations in temperature, rainfall and sea level pressure were documented. This mode of climate variability was then given the name “North Atlantic Oscillation” (NAO). More recently the phenomenon has been more strictly defined as the atmospheric pressure difference between Iceland and the Azores (Marshall and Kushnir 1997). A high NAO index is characterised in the Northeast Atlantic by a reinforcement of the westerlies that are pushed further south, and hence by warmer winter temperatures than normal. On the other hand, a low NAO index is typical of weakened westerlies that are moved far north and by colder winter

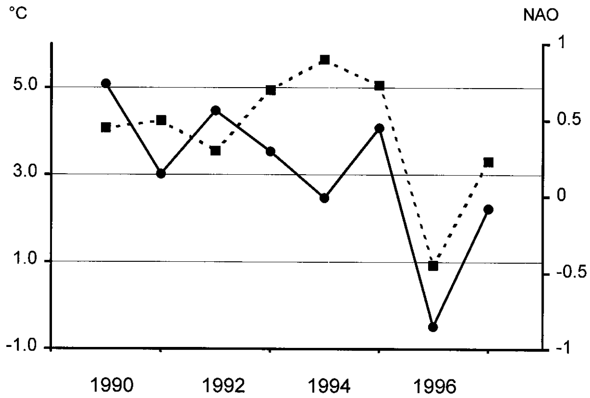

Fig. 4 Winter water temperature (°C; ●—●) in the Sylt-Rømø tidal basin and NAO winter index (December to March; ■---■) in the years 1990–1997

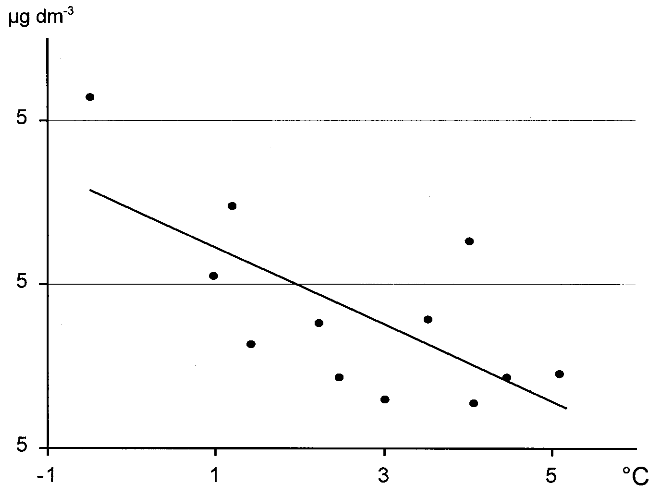

Fig. 5 Spearman rank correlation between the water temperature in winter (°C) and the mean spring (March to June) chlorophyll *a* concentration (µg dm^{-3}) in the Sylt-Rømø tidal basin, *R*=0.695, *P*<0.012

temperatures (Fromentin and Planque 1996). During the last 50 years, countries surrounding the Atlantic Basin have experienced dramatic changes in climatic conditions (Marshall and Kushnir 1997). Since the mid-1960s there has been a steady increase in winter storminess in the Northeast Atlantic and the North Sea with an upward trend in winter rainfall while winter temperatures rose steadily. However, these climatic trends may now be reversing (Marshall and Kushnir 1997).

These large-scale atmospheric fluctuations also affect the Sylt-Rømø tidal basin. There is a significant (*P*<0.05) linear correlation between the NAO winter index (December–March) from 1990 to 1997 and the winter temperature of the seawater in the Sylt-Rømø tidal basin (Fig. 4). In turn, the winter temperature of the water correlates significantly negatively with the amount of chlorophyll *a* found during the spring season (Fig. 5). These correlations indicate that large-scale atmospheric fluctuations, as expressed by the NAO winter index, may be a major reason for the interannual variability in the chemistry and biology of the Sylt-Rømø tidal basin. This includes direct and local effects such as air temperature, as well as indirect effects such as precipitation in the catchment area of the Elbe river, that affect the Sylt-Rømø tidal basin after a 1 month delay.

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