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RECENT CHANGES IN THE CONTRIBUTIONS OF RIVER RHINE AND NORTH SEA TO THE EUTROPHICATION OF THE WESTERN DUTCH WADDEN SEA

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KEYWORDS: Eutrophication, nutrients, phosphorus, nitrogen, chlorophyll-*a*, primary production, secondary production, *Mytilus edulis*, river Rhine, Wadden Sea, North Sea.

ABSTRACT

From 1955 to the mid 1980s the loads of both nitrogen and phosphorus from the river Rhine to the Dutch coastal area, the Wadden Sea included, increased. Since 1985 the phosphorus loads has decreased significantly, while the nitrogen load remained about the same.

Annual primary production in the western Dutch Wadden Sea has increased from *c.* 40 g C m^{-2} (1950) to 150 (mid 1960s) and over 500 g C m^{-2} (1986). The biomass of macrozoobenthos has more than doubled since 1970. Simultaneously, the meat yield of cultured blue mussels (*Mytilus edulis*), has increased since the 1960s. Previously, it was indicated that the increase in primary production of the phytoplankton over the period 1950 to 1986 was stimulated by the load of dissolved inorganic phosphate from Lake IJssel, a reservoir supplied by Rhine water. Since 1990, however, primary production has been higher than was expected from decreased phosphate loads from Lake IJssel. It is argued that this lack of response may have been caused by increased concentrations of dissolved inorganic phosphate at sea originating from increased inflow from a.o. the Strait of Dover, which compensate for the decrease in phosphate from the rivers, possibly in combination with a significant improvement of the light conditions of the water in the Wadden Sea.

INTRODUCTION

Some years ago, it was hypothesized that increased primary production in the western Dutch Wadden Sea was caused by the load of dissolved inorganic phosphate (DIP) from Lake IJssel (DE JONGE 1990). BODDEKE and HAGEL (1991), however, argued that changes in fish stocks in Dutch coastal waters were the result of decreased load of DIP from the river Rhine catchment area. Despite the strong decrease in the phosphate loads by the river Rhine and its trubutaries, CADÉE and HEGEMAN (1993) reported that primary production remained high in the western Dutch Wadden Sea. This finding seems contradictory to that of DE JONGE (1990) and also to the explanation put forward by BODDEKE and HAGEL (1991). It also poses a management problem because so far the reduction of DIP load did not result in the expected decrease of primary production in the western Wadden Sea.

If all other conditions are favourable for algal growth, an increase in nutrient load will result in a higher production of algae. However, the final expression of eutrophication in coastal areas is not only related to the nutrient loads of the rivers but also to the background levels of nutrients in the sea. In turn, these background levels are governed by the nutrient loads towards the North Sea system from the Strait of Dover and the Orkney and Shetland region in the northern North Sea. Further, it can be argued that the final expression of eutrophication in the western Dutch Wadden Sea is also influenced by local changes in the turbidity of the water.

In this paper, the historical changes in nutrient concentrations in the western Dutch Wadden Sea and nutrient loads from the river Rhine and Lake IJssel are presented and related to changes in nutrient concentrations of the water entering the North Sea. Moreover, changes in the turbidity of the water in the western Dutch Wadden Sea are considered. Responses of primary producers will be related to changes in the above mentioned parameters. It will be explained that at present the influence of the North Sea on the productivity of the western Dutch Wadden Sea may be much more important than in the past. It will be demonstrated that the relationship between nutrient loads from the rivers and productivity of the western Dutch Wadden Sea cannot be analysed in isolation, *i.e.* based solely on statistical treatment of the available data.

MATERIALS AND METHODS

Study area

The Dutch Wadden Sea is a shallow well-mixed inshore area in the northwestern part of The Netherlands. The western Dutch Wadden Sea (Fig. 1) covers approximately 1500 km^2 and is composed of three tidal basins which are separated from the North Sea by barrier islands and from the mainland by dikes. The tidal inlets between the islands (Marsdiep-Vliestroom) allow water exchange with the North Sea. The residence time of freshwater is *c.* 12 days (ZIMMERMAN, 1976). In the westernmost part, a 50 km^2 intertidal flat area (Balgzand) is situated.

The catchment of the western Dutch Wadden Sea is mainly the drainage basin of the river Rhine which comprises an area of *c.* 185,000 km^2.

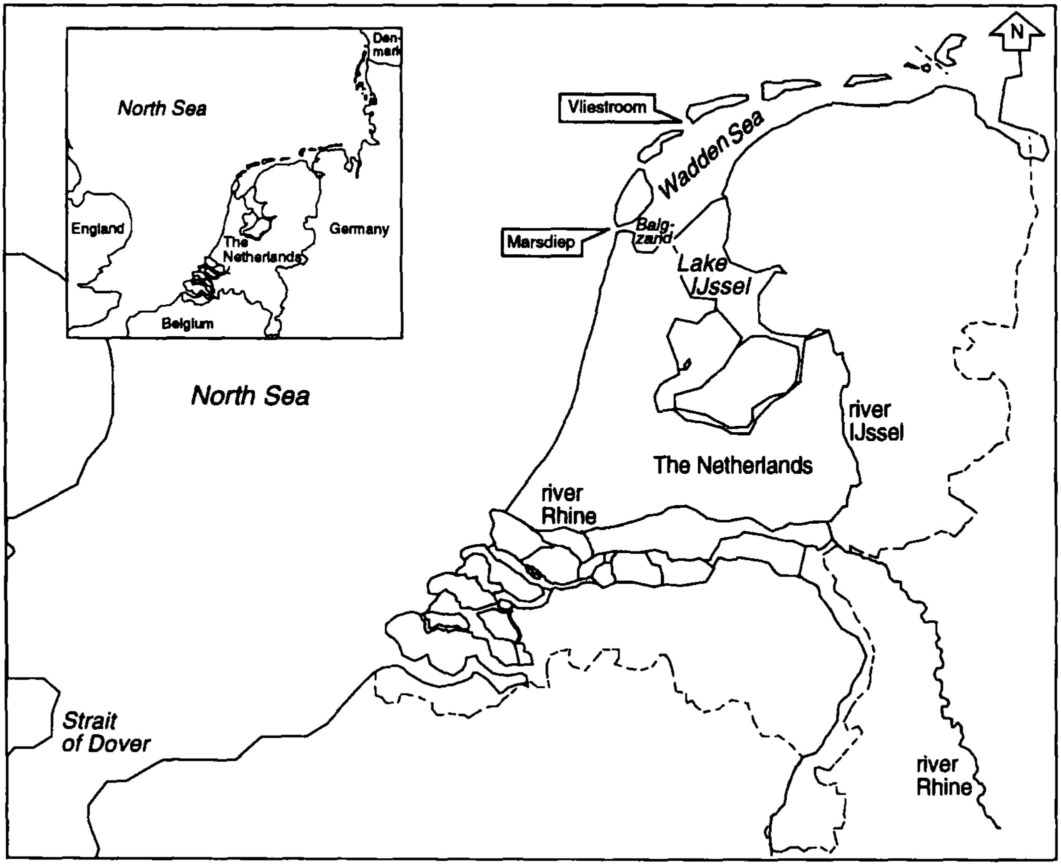


Fig. 1. Map of eastern part of the Southern Bight of the North Sea, the Dutch coastal zone and the western Dutch Wadden Sea. Tidal inlets Marsdiep and Vliestroom, and Balgzand intertidal flat area are indicated.

The water discharge of river Rhine varies strongly. The long-term average is *c.* 2200 m^3 s^{-1}. Directly downstream of the Dutch-German border the Rhine branches. Two of these branches flow westward and enter the North Sea area in the southwestern part of The Netherlands where the river water mixes with sea water from the Straits of Dover flowing in a northeasterly direction. The third branch (river IJssel) flows northward into the freshwater reservoir Lake IJssel (Fig. 1) from where on average 300 - 600 m^3 s^{-1} is discharged into the Wadden Sea through sluices. In the Wadden Sea the water from Lake IJssel mixes with coastal water, which in turn consists of a mixture of North Sea water and river Rhine water. The freshwater content in the westernmost tidal inlet (Marsdiep) is about 13%. Approximately 60% of this freshwater originates from Lake IJssel (ZIMMERMAN, 1976). The total (direct and indirect) freshwater supply to the western Dutch Wadden Sea ranges from 500 to 1000 m^3 s^{-1} (RIDDERINKHOF, 1988).

Source of data and analyses

Nutrient data were derived from the Rijkswaterstaat (part of the Ministry of Traffic, Public Works and Water Management) monitoring data files and LAANE *et al.* (1993). Analysis of nutrient concentrations in water samples was based on GRASSHOFF *et al.* (1983).

Data on phytoplankton primary production were taken from POSTMA, 1954; POSTMA and ROMMETS, 1970; CADÉE and HEGEMAN (1974a,b, 1979, 1993), CADÉE (1980, 1986) and VELDHUIS *et al.* (1988). Most primary production measurements were based on the ^{14}C method (*cf.* STEEMANN NIELSEN, 1952). The 1950 estimate, made before the ^{14}C method was developed, was based on the growth rate of algae (*cf.* POSTMA, 1954).

Chlorophyll-*a* and suspended matter data were also obtained from the Rijkswaterstaat data files. Chlorophyll-*a* was initially determined according to LORENZEN (1967). Since 1986, HPLC was applied following the method of GIESKES and KRAAY (1984). Biomass data on intertidal macrozoobenthos, based on samplings in March of 12 transects and 4 permanent quadrats on Balgzand (Fig. 1) were obtained from BEUKEMA and CADÉE (1986) and BEUKEMA (1989). More recent data were made available by Dr. J.J. Beukema.

Data on meat content of the blue mussel cultured in the Wadden Sea were made available by the Netherlands Institute for Fisheries Research at Yerseke. Data on historical changes of turbidity and suspended matter were taken from DE JONGE and DE JONG (1992).

Statistical methods

Because of the low number of observations and the presumption of non-normality, Spearman's rank correlation coefficients were used to determine the statistical significance of observed relationships between parameters. Statistical treatment was carried out with SPSS 5.0 package.

RESULTS

Primary producers

Annual primary production of phytoplankton in the Marsdiep tidal inlet showed significant variation over time (Fig. 2) ranging from the lowest estimate of 20-40 g C m^{-2} for the early 1950s (POSTMA, 1954) to the highest value of 520 g C m^{-2} for 1981 and 1982 based on CADÉE (1986). CADÉE (1986) gave a much lower value for the 1981-82 primary production but according to Fig. 2 (p. 287) of this publication the annual production should have been much higher. Microphytobenthos showed the same production pattern as given for phytoplankton (Fig. 2). Striking is the general increase in the phytoplankton primary production up to the early 1980s, then followed by a decrease. For the inner area of the Marsdiep tidal basin, with only a few measurements available, the pattern is in agreement with that for the inlet. Also the annual mean chlorophyll-*a* concentrations in the Marsdiep tidal inlet showed a clear increase over time (Fig. 3). However, although the observed increase in chlorophyll-*a* has been nearly threefold, it was less pronounced than the increase in the annual primary production.

Primary consumers

The biomass of intertidal macrozoobenthos in the western Dutch Wadden Sea (Balgzand) roughly doubled over a period of *c.* 20 years (Fig. 4). This change is consistent with the increase of annual primary production (Fig. 2) and chlorophyll-*a* over the same period (Fig. 3). The response of macrozoobenthos was not proportional to the variation in primary production and chlorophyll-*a*. This difference suggests that also other factors are governing the interannual variations in the biomass of macrozoobenthos.

The meat content of the blue mussel (*Mytilus edulis* L.) showed a steady increase since *c.* 1970 (Fig. 5). This observation also indicates that in the

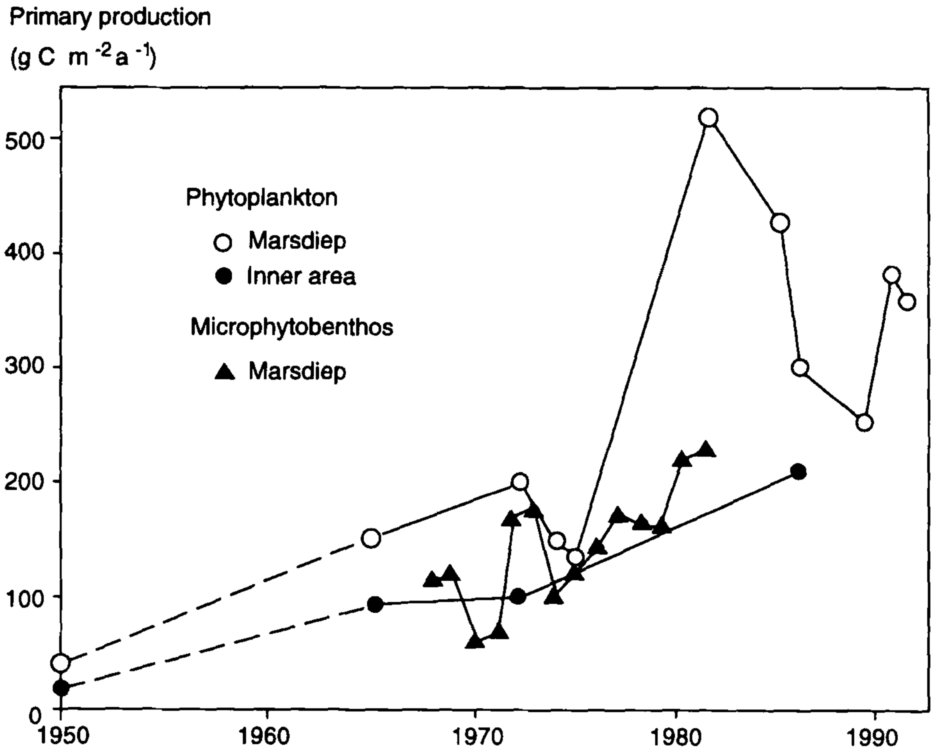


Fig. 2. Time series of the annual primary production by phytoplankton and microphytobenthos in the western Dutch Wadden Sea (Marsdiep tidal inlet and inner area of Marsdiep tidal basin).

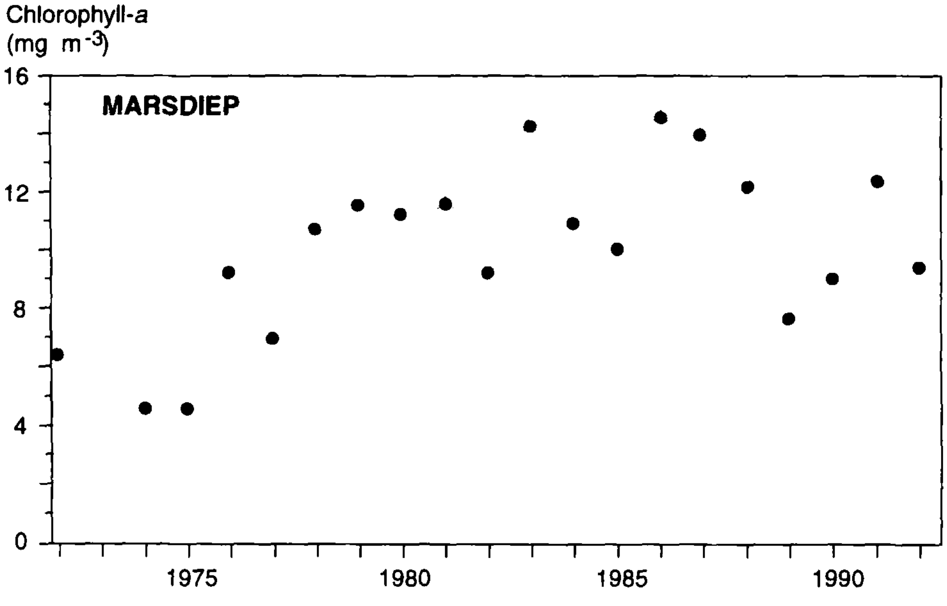


Fig. 3. Time series of annual mean concentrations of chlorophyll-*a* in the Marsdiep tidal inlet.

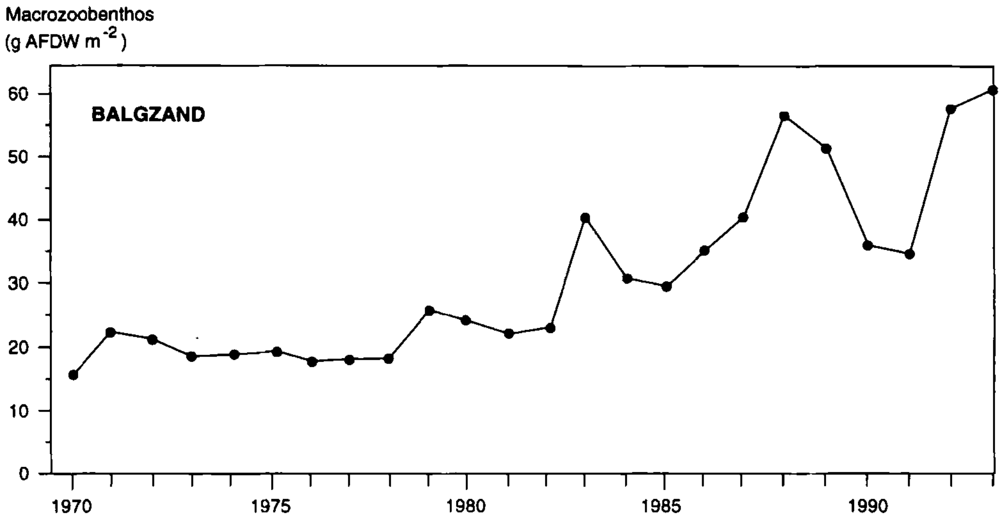


Fig. 4. Time series of the mean biomass of total macrozoobenthos of Balgzand (for location see Fig. 1) in March. Data from BEUKEMA (1989), supplemented with recent data by Dr. J.J. Beukema (Netherlands Institute for Sea Research).

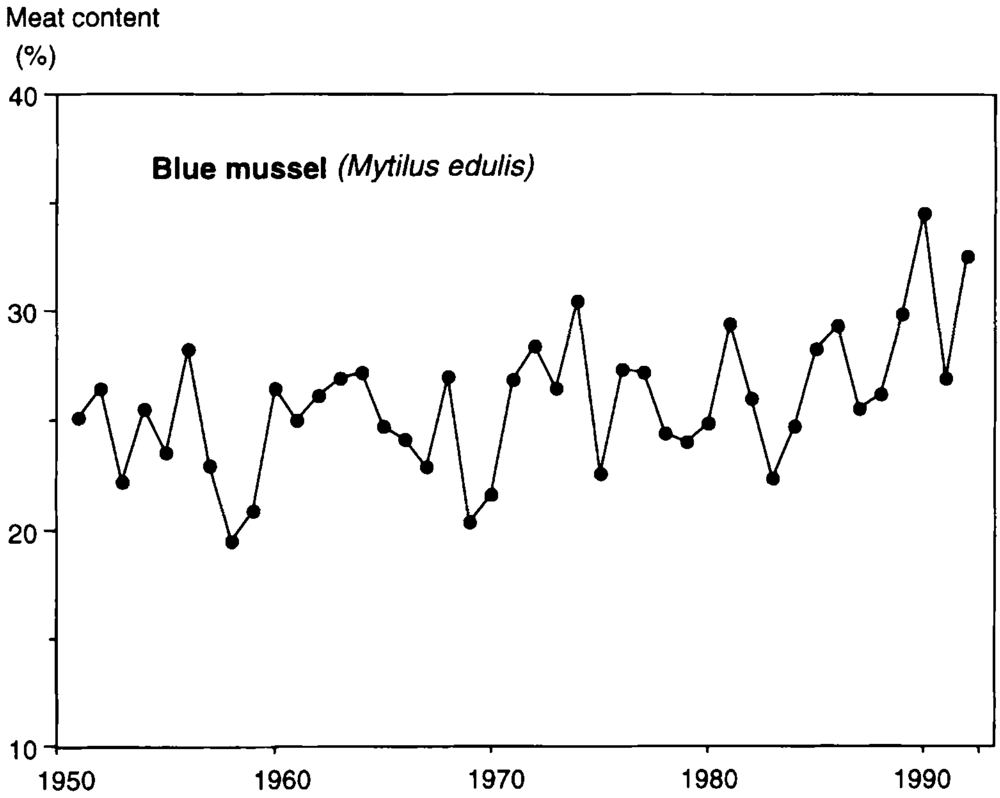


Fig. 5. Time series of mean meat content of cultured blue mussel in the western Dutch Wadden Sea.

western Dutch Wadden Sea growth conditions for primary consumers have improved over a long period of time.

Nutrient loads of river Rhine and Lake IJssel

Fig. 6 presents the nutrient loads of the river Rhine, as calculated for the border between The Netherlands and Germany, and at the boundary between Lake IJssel and the Wadden Sea (*cf.* Fig. 1).

The curves for the river Rhine show a tremendous increase in the loads of DIP and total phosphorus from the 1950s onwards. The dissolved inorganic nitrogen load increased only till the mid 1960s, whereas DIP continued to increase for a longer period. However, since the early 1980s the loads of both total phosphorus and DIP have decreased. Since the late 1980s the load of dissolved inorganic nitrogen also tends to decrease. The fluctuations in the loads have been large. For total nitrogen there are no data from before 1967. So, we do not know whether the trends for nitrogen and phosphorus prior to 1970 were similar.

Fig. 6 also presents the nutrient loads from

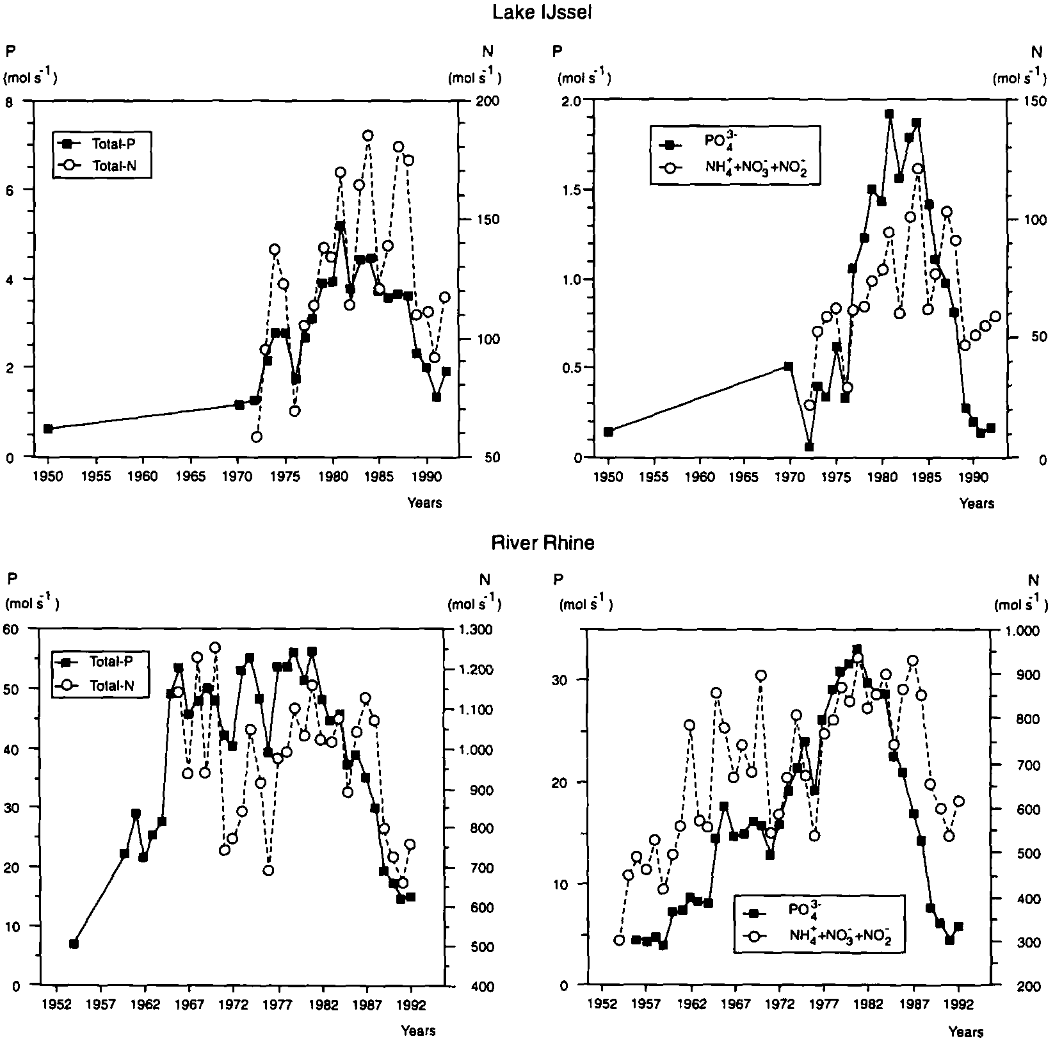


Fig. 6. Loads of nutrients from IJsselmeer to the Wadden Sea (upper panels) and in the river Rhine on the Dutch-German border (lower panels).

Lake IJssel to the Wadden Sea. The loads of both DIP and total phosphorus increased steeply from 1971 to 1984. Since 1984 these loads have decreased. The loads of dissolved inorganic nitrogen and total nitrogen varied parallel to those of phosphorus compounds. In the 1980s, the phosphorus load decreased to be followed by the nitrogen load, just as reported for the river Rhine. The annual mean atomic N:P ratio in the freshwater discharged into the Wadden Sea always exceeded the Redfield ratio of 16, indicating that phosphorus rather than nitrogen was the limiting factor for algal growth.

Nutrient concentrations in Marsdiep and Strait of Dover

In the Marsdiep tidal inlet the annual mean concentrations of DIP, as well as those in winter showed a clear decrease from the mid 1980s onwards (Fig. 7), notwithstanding an exceptionally high winter value of DIP in 1986.

These changes did not correspond well to the decreased phosphorus loads from the river Rhine and Lake IJssel. The loads of total phosphorus from Lake IJssel and the river Rhine decreased by a factor 3.5. The load of DIP from the river Rhine decreased by factor 7 and that from Lake IJssel by factor 10. The DIP concentrations in the Marsdiep tidal inlet, however, decreased by factor of 2 only over the period considered. Neither the annual mean nor the winter concentrations of dissolved inorganic nitrogen showed a clear trend. This is in accordance with the absence of significant change in the nitrogen loads. In the Straits of Dover the winter concentrations of dissolved inorganic nitrogen and DIP suggest that a two- to threefold increase may have occurred since 1965 (Fig. 8).

Turbidity in Marsdiep

Between 1973 and 1984 total suspended matter concentrations, increased fourfold, to be followed by a rapid decrease (Fig. 9). Unfortunately, the data series is rather short and no data are available for the period 1951 to 1969.

Relations between variables

In order to find correlations between parameters, for the period 1950-1992 two different data sets were investigated. The first data set consists of values for the years in which primary production was measured in the Marsdiep tidal inlet (*cf.* Fig. 2). The second data set is based on the years during which chlorophyll-*a* was measured in the Marsdiep tidal inlet (*cf.* Fig. 3).

Rank correlation test results showed a highly significant positive correlation (r = 0.74, P = 0.024) between the annual primary production and the annual mean chlorophyll-*a* concentration in the Marsdiep tidal inlet (Table 1). A nearly significant positive correlation (r = 0.64, P = 0.052) was also found between the annual primary production and the load of DIP from Lake IJssel.

Because the data sets for primary production and chlorophyll-*a* were of unequal length it was decided also to investigate the correlation between chlorophyll-*a* and DIP from Lake IJssel for the years for which primary production data are available. For these nine years no significant correlation between chlorophyll-*a* and the load of DIP from Lake IJssel was found (r = 0.40, P = 0.291.

For the entire time series of chlorophyll-*a*

Table 1. Results of correlation analysis between primary production in the Marsdiep tidal inlet and various parameters for river Rhine, Lake IJssel, and Marsdiep tidal inlet. DIP = dissolved inorganic phosphate, DIN = total dissolved inorganic nitrogen, turbidity = attenuation coefficient (K_z). Significant correlations in bold.

Load river Rhine	DIP r = 0.30 n = 11 P = 0.368	Total-P r = 0.10 n = 10 P = 0.786	DIN r = 0.41 n = 11 P = 0.209	Total-N r = −0.16 n = 10 P = 0.668
Load Lake IJssel	DIP r = 0.63 n = 10 P = 0.052	Total-P r = 0.59 n = 10 P = 0.070	DIN r = 0.49 n = 9 P = 0.182	Total-N r = 0.19 n = 9 P = 0.619
Marsdiep inlet	Turbidity r = 0.46 n = 10 P = 0.185	DIP r = 0.41 n = 10 P = 0.244	DIN r = −0.47 n = 8 P = 0.238	**Chl-a** **r = 0.74** **n = 9** **P = 0.024**

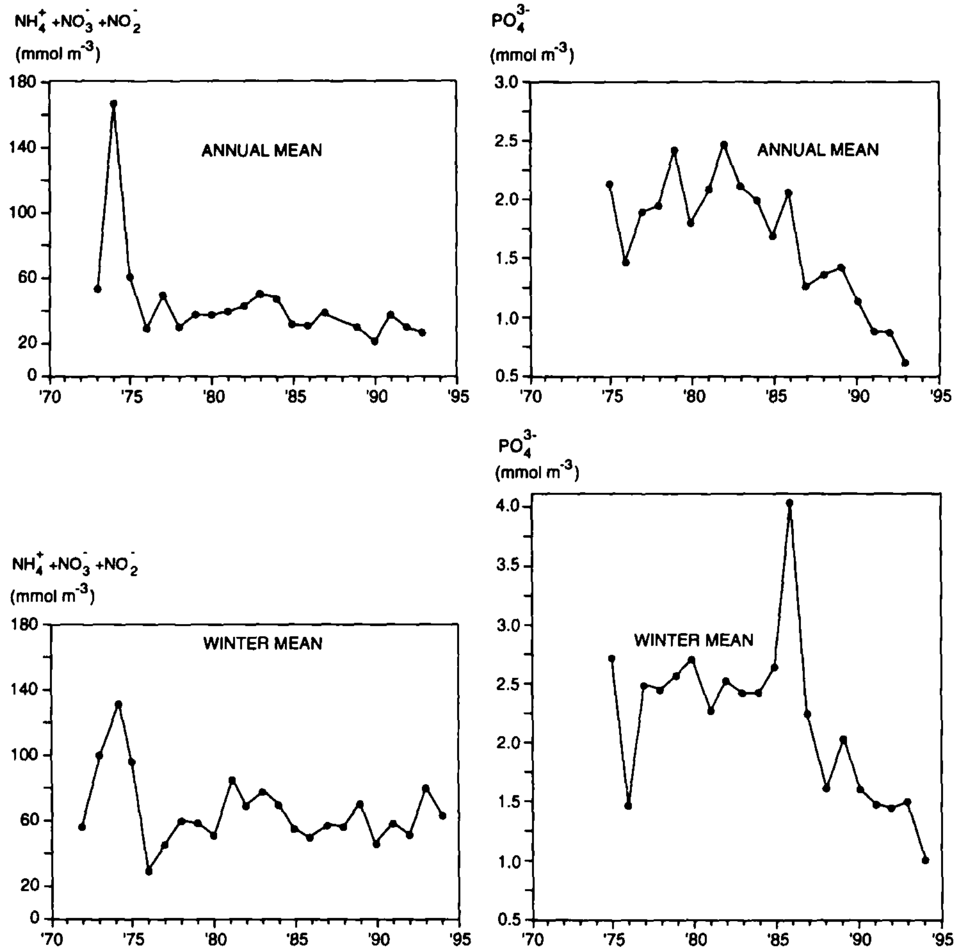
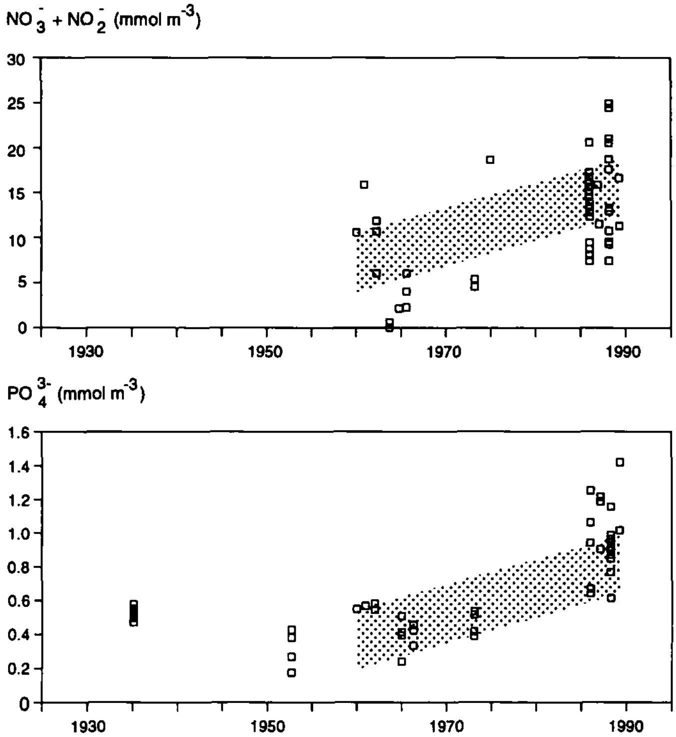


Fig. 7. Annual mean concentrations and mean winter (Dec.-Feb.) concentrations of dissolved inorganic nitrogen and dissolved inorganic phosphate in the Marsdiep tidal inlet.

Table 2. Result of correlation analysis between chlorophyll-*a* concentration in the Marsdiep tidal inlet and parameters for river Rhine, Lake IJssel, and Marsdiep tidal inlet. See Table 1 for explanation. Prim. prod. = annual primary production.

Load river Rhine	DIP r = 0.11 n = 20 P = 0.635	Total-P r = −0.13 n = 20 P = 0.598	**DIN** **r = 0.46** **n = 20** **P = 0.042**	Total-N r = 0.33 n = 20 P = 0.151
Load Lake IJssel	**DIP** **r = 0.48** **n = 20** **P = 0.033**	**Total-P** **r = 0.4802** **n = 20** **P = 0.032**	**DIN** **r = 0.60** **n = 20** **P = 0.005**	**Total-N** **r = 0.51** **n = 20** **P = 0.021**
Marsdiep	Turbidity r = 0.34 n = 20 P = 0.138	DIP conc r = 0.17 n = 20 P = 0.480	DIN conc r = −0.35 n = 19 P = 0.137	**Prim. prod.** **r = 0.74** **n = 9** **P = 0.024**

Fig. 8. Winter concentrations of dissolved inorganic nitrogen and dissolved inorganic phosphate in the central part of the Strait of Dover.



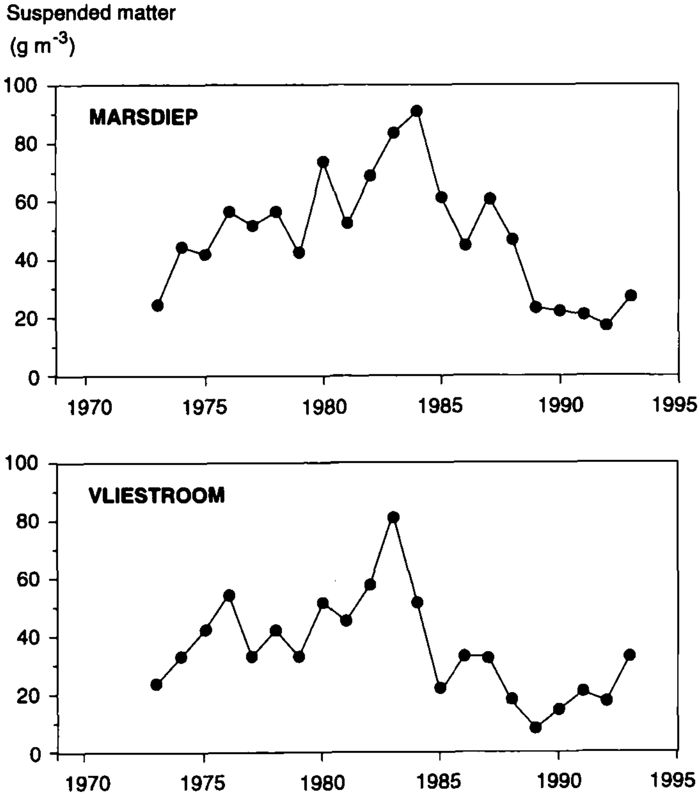


Fig. 9. Time series of annual mean concentrations of suspended material in two tidal inlets in the western Dutch Wadden Sea. Data from Rijkswaterstaat.

Table 3. Nutrient fluxes (mol s^{-1}) through the Strait of Dover, the river Rhine (at the border between The Netherlands and Germany) and Lake IJssel in 1986-1988. Data on Strait of Dover from LAANE *et al.* (1993); other data from Rijkswaterstaat.

	DIN	Total N	Ortho-phosphate	Total P
Strait of Dover	1237	3196	81	196
River Rhine	899	1111	18	35
Lake IJssel	89	165	1	3.5

(1972-1992), a significant positive correlation was found between chlorophyll-*a* concentration in the Marsdiep tidal inlet and load of DIN from the river Rhine, and the load of the nutrient fractions from Lake IJssel (Table 2). The lowest correlation (r = 0.46) was with the load of DIN from the river Rhine while the highest (r = 0.60) was with the DIN load from Lake IJssel. The overall picture of these results is not in good agreement with that for the primary production data set (Table 1). This may be due to the difference in data set length. To investigate this, the correlation between chlorophyll-*a* concentration in the Marsdiep tidal inlet and load of DIN from Lake IJssel was also investigated for the limited number of years (n = 9) that primary production data were available. This analysis did not result in a statistically significant relationship (r = 0.53, P = 0.140), whereas the longer data series with 20 observations (Table 2) did show a highly significant relationship (r = 0.60, P = 0.005).

From these results it is clear that the correlations between chlorophyll-*a* concentration in the Marsdiep tidal inlet and the DIN or DIP load from Lake IJssel for the years in which annual primary production was measured, were not significant. Neither was there a significant correlation between primary production and the Lake IJssel load of DIN, whereas the correlation between primary production and Lake IJssel load of DIP was statistically significant. Although for the Marsdiep tidal inlet a significant correlation was found between chlorophyll-*a* concentration and primary production, the correlation between chlorophyll-*a* concentration and DIP load from Lake IJssel was not significant.

DISCUSSION

The results show that in the western Dutch Wadden Sea, despite the decrease in the DIP loads since the early 1980s, the productivity of phytoplankton and macrozoobenthos as well as the meat content of mussels remained high. This observation suggests that nitrogen rather than phosphorus is the primary growth limiting factor for algae in this area. There are, however, other hypotheses to explain the observed developments. One is that decreased turbidity (see Fig. 9) compensated for a decreased nutrient supply to phytoplankton. The other is a change in the influence of the North Sea (*cf.* Fig. 8) relative to that of the river Rhine and Lake IJssel (*cf.* Fig. 6). These possibilities will be further discussed below.

Particulate nutrients

Dissolved nutrients from the river Rhine may reach the Wadden Sea by direct water transport along the Dutch coast. If nutrients are incorporated in organic particles or adsorbed to or included in sediment particles, their transport path may differ considerably. The magnitude of the import of the particulate fraction of phosphorus from the North Sea coastal zone to the Wadden Sea is not well quantified but may vary between 0.19 mol P m^{-2} a^{-1} (DE JONGE and POSTMA, 1974) and zero (VAN RAAPHORST and VAN DER VEER (1990). The variation in import of particulate material is dependent on the efficiency of the accumulation mechanism which in turn is dependent on the asymmetry of the tidal curve and accompanying residual currents. VAN RAAPHORST and VAN DER VEER (*op. cit.*) have suggested that during the late 1980s the Wadden Sea may not have been a nutrient (sediment) importing system. This means that here we only have to consider the nutrient fractions that reach the Wadden Sea in dissolved state or suspended as very fine particulate material.

Nutrient release from sediments

An aspect not dicussed so far is release of nutrients from bottom sediments. Part of the nutrients found in the water column are leached from the bottom sediments after desposition of suspended material (DE JONGE *et al.*, 1993). The main conclusion from that study was that the role of the bottom as a net source for phosphorus is not dominant under the present conditions of decreasing inputs. In the sediments large amounts of phosphorus are available. However, roughly 80% is not available for algal growth on the shorter term (*i.e.* within one growing season) as it is mainly calcium associated. If we assume that in the western Dutch Wadden Sea the remaining 20% biologically available phosphorus in the top

10 cm sediment layer can be used for algal growth within one growing season, we arrive at a load of 0.8 mol s^{-1}. This load is comparable to the load of Lake IJssel in the mid 1970s and in 1987, and can account for a total primary production of approx. 250 g C m^{-2} a^{-1}.

Influence of North Sea, river Rhine and Lake IJssel

As mentioned above, the water in the western Dutch Wadden Sea is mainly (85%) sea water, while the contributions from the river Rhine and Lake IJssel are approximately equal and accounting for the remaining 15%. The sea water in the western Dutch Wadden Sea originates mainly from the southern North Sea which receives water and nutrients from rivers and the Strait of Dover. The water coming from the Strait of Dover, together with the sea water entering the area from the north, determines to a great extent the basic levels of nutrient concentrations in Dutch coastal waters. The nutrient concentrations in the Strait of Dover have possibly increased 2 to 3 times from the early 1930s to the period 1986 to 1988 (LAANE *et al.*, 1993; see also Fig. 8). Firm evidence for the correctness of such a change can not be given, due to lack of data and the use of different chemical methods in the past.

When, for the period 1986-1988, the nutrient fluxes through the Strait of Dover (*cf.* LAANE *et al.*, 1993) are compared with those of the relevant sources for the Wadden Sea (river Rhine and Lake IJssel; Table 3), the dominance of the Strait of Dover in the supply of nutrients to the southern North Sea is evident. Approximately 19% of the DIP originates from the Rhine while 1% comes indirectly from the Rhine by Lake IJssel. The other 81% comes from the Strait of Dover. For dissolved inorganic nitrogen the total contribution by the river Rhine is *c.* 45%. The values for total phosphorus are roughly comparable with those of DIP while the relative input of total nitrogen by the Strait of Dover is even larger than that of dissolved inorganic nitrogen.

The information presented above strongly suggests that for phosphorus, and to les extent for nitrogen, the relative influence of the sea water in the western Dutch Wadden Sea has increased concomitantly with the reduction of the nutrient loads of the rivers. More support for this suggestion is derived from the relatively weak decrease in DIP concentration in the Marsdiep as compared with the strong decrease in the phosphorus river load (*cf.* Figs. 6 and 7; *cf.* also BAKKER *et al.*, 1994). Therefore, we hypothesize that the persisting high primary production levels in the western Dutch Wadden Sea (CADÉE and HEGEMAN, 1993) as well as the high biomass of macrozoobenthos (Fig. 4; see also BEUKEMA, 1989, 1991) and high meat content of the blue mussel (Fig. 5) may well be explained by increased nutrient levels at sea counteracting the recent reduction in the river loads of phosphorus.

It is further suggested that the changing influence of rivers and sea on the productivity of the western Dutch Wadden Sea may also be one of the explanations for the lack of significant correlation between the primary production and the DIP load from Lake IJssel in the pre-1987 and post-1987 periods. Unfortunately, a more direct explanation is not possible because no reliable estimates of nutrient loads from North Sea to the western Wadden Sea are available.

In finding an explanation for the observed phenomena, we have focussed on phosphorus and not on nitrogen because of the pronounced changes in the phosphorus loads over time. This certainly does not mean that nitrogen is considered not to play a significant role. The statistical methods used did not enable us to clearly discriminate between the effects caused by turbidity or nutrients. Therefore, we suggest to apply ecosystem modelling to further analyze this aspect.

Turbidity

Data covering a period of approximately 20 years show that the suspended matter concentrations and consequently the light conditions in the western Dutch Wadden Sea have changed (DE JONGE and DE JONG, 1992). The cause of this change is still not satisfactorily understood. However, these changes certainly have had an impact on the system. In the Marsdiep tidal channel changes in suspended matter concentrations have resulted in vertical light attenuation coefficients (K_z) ranging from 1.1 (in 1992) to 4.1 (in 1984). The consequences of these changes for the primary production of algae can be estimated. Compared to the situation with $K_z = 4.1$ (1984) the production under conditions with a $K_z = 1.1$ (1992) may have increased by factor 3.8 if all other factors governing the photosynthesisi – irradiance relationship would have remained unchanged.

Thus, based on the recently improved light conditions in the Wadden Sea (Fig. 9), relatively high production of phytoplankton and bivalves in the western part of the Dutch Wadden Sea may be foreseen. If, however, the turbidity increases again, this will negatively influence the productivity of the ecosystem.

Combined effects of nutrients and turbidity

The relative importance of the role of nutrients and light conditions in the functioning of an estuarine system can in a qualitative way be elucidated by referring to earlier work in the Ems estuary (DE JONGE and DEGROODT, 1989; DEGROODT and DE JONGE, 1990). From those studies it was concluded that in relatively turbid estuarine areas, such as the Ems estuary and the western Dutch Wadden Sea, an improvement in water transparency is of more benefit for the productivity than an increased nutrient supply. Therefore, it can be assumed that the improvement in light conditions in the western Dutch Wadden Sea also had a significant effect.

In order to get firm evidence for the contribution of both light and nutrients to the productivity in the western Wadden Sea a computer simulation model will be applied. The results of this approach will be reported separately.

CONCLUSIONS

Based on the arguments given in this paper it is hypothesized that at present the effects of the influx of bio-available phosphorus from the North Sea to the Wadden Sea are more important than those of the phosphorus loads from the rivers. This condition can be explained by an increase in the concentrations at sea in combination with a decrease in the river load.

From a management point of view it is recommended to pay more attention to the nutrient dynamics in the source areas of the nutrients to be transported to the Wadden Sea.

Because the turbidity in the Wadden Sea shows long-term variations, it is recommended to relate management targets for nitrogen and phosphorus to both total primary production (and total chlorophyll-*a*) and turbidity.

Finally, it is clear that the judgement of the trophic state of the Wadden Sea can not simply be determined based solely on nutrients. We also have to take into account other factors that limit the algal growth, *e.g.* the light conditions.

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