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On trends in nutrient concentration in the northern Wadden Sea of Sylt*

Peter Martens

Biologische Anstalt Helgoland, Wattenmeerinstitut List; D-2282 List/Sylt, Bundesrepublik Deutschland

ABSTRACT: The mean values on hydrographical parameters in the Wadden Sea of Sylt taken weekly over a period of seven years (1975, 1976 and 1984 to 1988) were compared in order to detect trends in concentrations of nutrients or plankton. An increase in NO_2, NO_3, PO_4 and Si could be found in summer. NH_4 showed a negative trend. Corresponding with the rising nutrient-level, chlorophyll-a and pH show a positive trend. Salinity decreased significantly. Changes in NH_4 and NO_2 were correlated with rainfall.

INTRODUCTION

The northern Wadden Sea of Sylt lies east of the northern part of the island of Sylt; it is separated from other parts of the Wadden Sea by two dams and is connected with the North Sea only by a relatively narrow tidal inlet, the Lister Deep (Fig. 1). Measurements on the biological oceanography of this part of the Wadden Sea have been performed since 1972. Several publications (Hickel, 1980, 1983, 1989; Martens, 1980, 1981, 1982, 1986a, 1986b) deal with the hydrography, phyto- and zooplankton of this area.

Since Radach & Berg (1986) have shown an increasing positive trend in the nutrient concentration in the German Bight and Hickel (1989) suggests an increase in phosphate-concentration in the northern Wadden Sea of Sylt, a comparison of the values taken over 6 years was carried out to verify trends in various hydrographical parameters.

MATERIALS AND METHODS

From May 1975 onwards, measurements have been performed twice a week, if possible, (depending on weather conditions), on the following hydrographical parameters (for position of station Lister Ley see Fig. 1):

(1) water temperature (reversing thermometer; ± 0.05 °C)
(2) salinity (Autosal 8400a Salinometer; ± 0.001 S)
(3) PO_4 (after Graßhoff, 1976)
(4) NH_4, NO_2 and NO_3 (after Graßhoff, 1976)
(5) Si (after Graßhoff, 1976)

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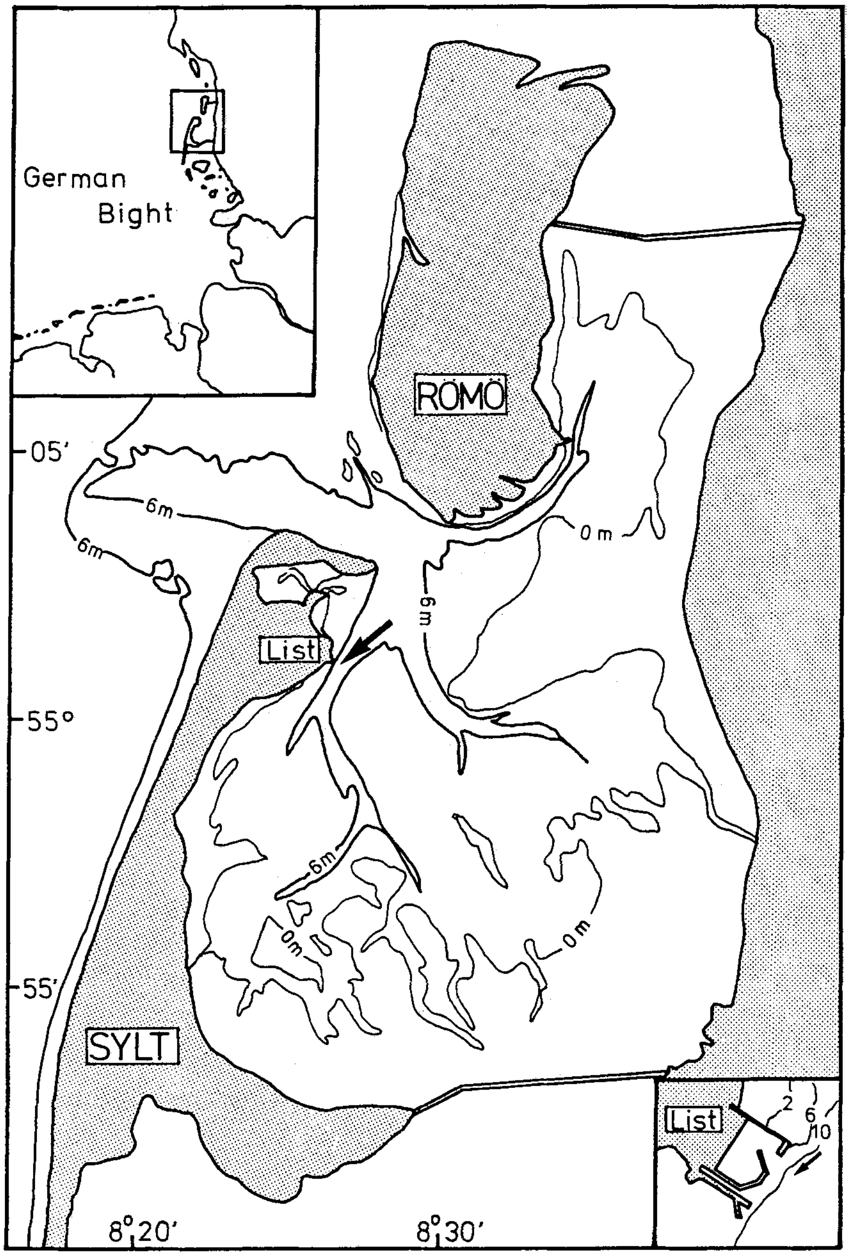

Fig. 1. Map of the northern Wadden Sea of Sylt with the sampling location Lister Ley (see arrow). Depths refer to mean spring low tide. Arrows indicate sampling location

(6) chlorophyll-a (UNESCO-standard-method)
(7) daily rainfall (Deutscher Wetterdienst, Wetterstation List).

The analyses were carried out on discrete watersamples taken with TPN-watersamplers near the surface. Strong turbulence prevents stratification in these waters (Hickel, 1975; Martens, unpubl. data).

Mathematical procedures

Between 1975 and 1988, seven years were chosen for statistical analysis where regular measurements from the same station were available (1975, 1976 and 1984–1988). Sets of data were tested for deviation from normal distribution by Chi^2-test, R/s-test and KS-test, and log-transformed when necessary.

Simple regression analyses were performed to show linear trends in the concentration of the parameters measured. To verify significant trends ($P < 0.05$), partial correlation analyses were performed to ascertain an influence of time on the concentration of the parameters when the tidal influence (temperature and salinity) was eliminated.

As some of the sets of data showed significant deviation from the normal distribution in at least one of the tests used, a Spearman-Rank-correlation was carried out to verify significant findings.

Finally, a stepwise variable selection was performed for all parameters that had shown a significant trend. If, in addition to the methods mentioned above, the addition of the time-factor to the prediction-model gave a significantly better result (F-test), a positive or negative trend was assumed.

The statistical analyses were performed with STATGRAPHICS Statistical Graphics System version 2.6.

RESULTS

Figure 2 gives the water temperature during the annual cycle for all 6 years. Little variability is to be seen in contrast to salinity (Fig. 3).

To ascertain trends (decrease or increase) in this or other parameters, the data were

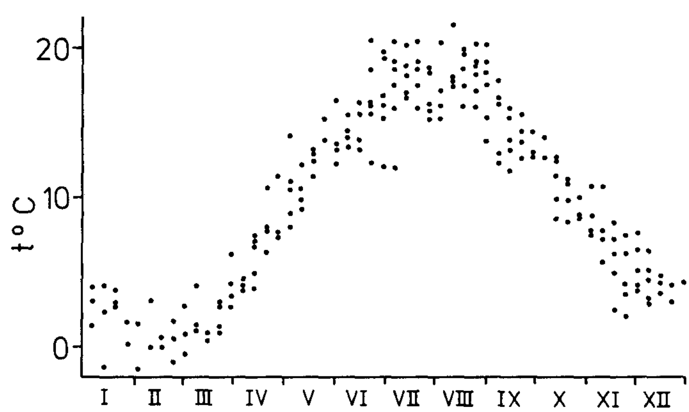

Fig. 2. Water temperature (°C) in the Wadden Sea of Sylt. Annual cycle over six years of investigation

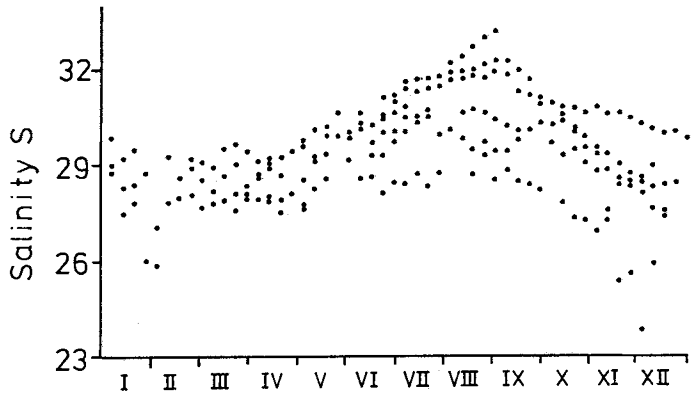

Fig. 3. Salinity S in the Wadden Sea of Sylt. Annual cycle over six years of investigation

grouped according to different "ecological seasons"; these were winter (December 15th to March 15th), spring (March 15th to May 31st), nutrient summer-minimum (June 1st to August 31st) and zooplankton summer/autumn-maximum (June 15th to September 31st).

Nearly all nutrients measured show a positive trend from 1975 to 1988, as can be seen in Figures 4 to 7 and Table 1.

NO_2 (Fig. 4) shows an increase of at least 300 % from the mid-seventies to 1988; the same is true for NO_3 (Fig. 5) which shows concentrations of up to 12 μgat l^{-1} in summer, values which were reached only in winter 10 years ago.

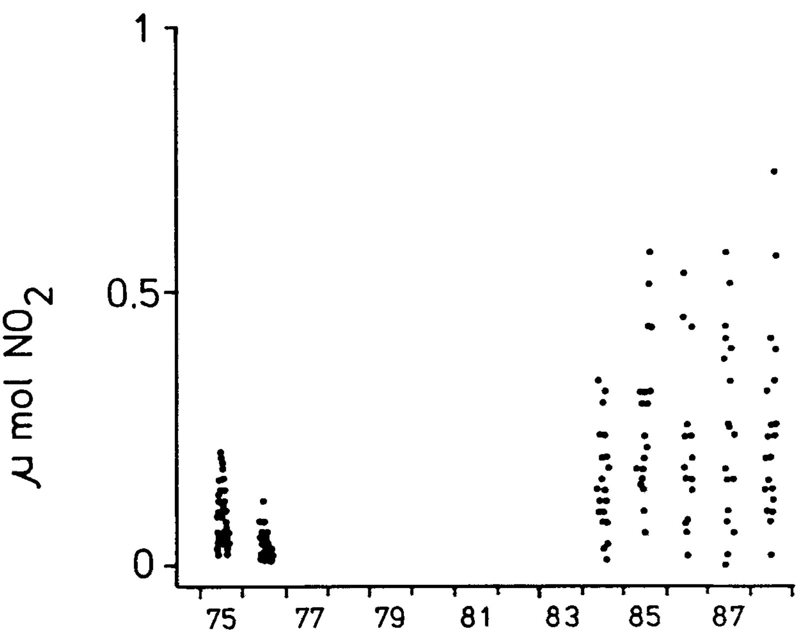

Fig. 4. NO_2 in μgat l^{-1} in different years in summer. X-axis = year. Y-axis = NO_2

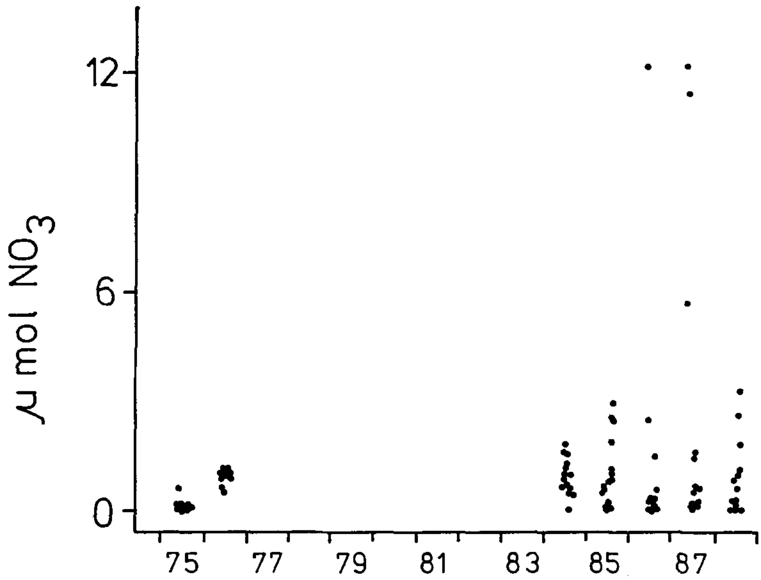

Fig. 5. NO_3 in μgat l^{-1} in different years in summer. X-axis = year. Y-axis = NO_3

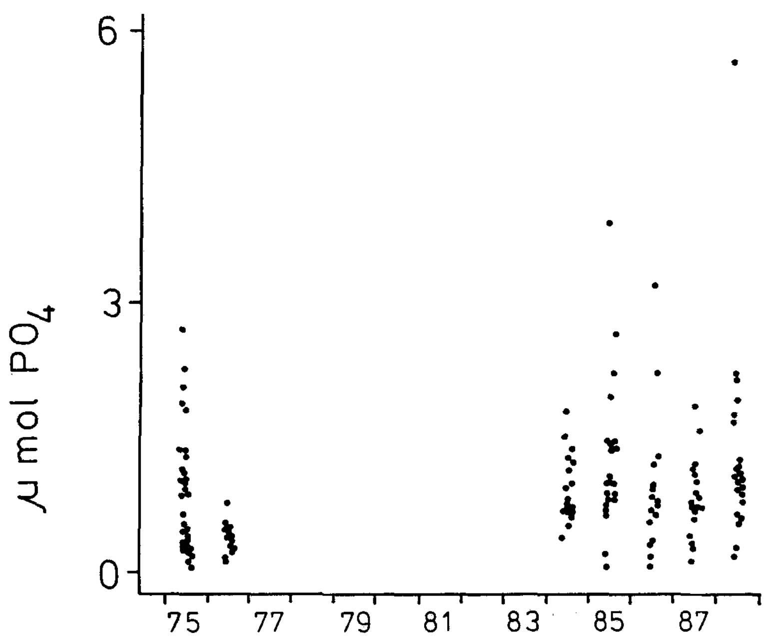

Fig. 6. PO_4-concentration in μgat l^{-1} in different years in summer. X-axis = year. Y-axis = PO_4

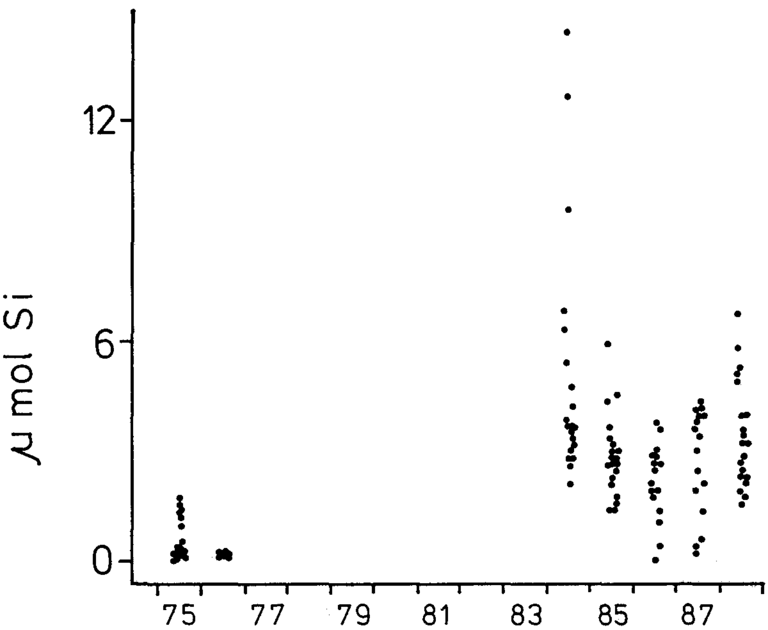

Fig. 7. Si in μgat l^{-1} in different years in summer. X-axis = year. Y-axis = Silicate

The changes in PO_4-concentration are not so drastic (Fig. 6) as those in silicate (Fig. 7) which shows minima of less than 1μgat l^{-1} only on one or two days during the year.

NH_4 is the only nutrient measured which showed a negative trend over the years (Fig. 8). This is due to very high values in the mid-seventies and a shift in the relation of NH_4–NO_2–NO_3, as can be seen by a comparison of Figures 4, 5 and 8.

For chlorophyll and pH, measurements started as late as 1984. Nevertheless, significant positive trends could be ascertained for both parameters as can be seen by Table 1 and Figures 9 and 10.

A stepwise variable selection analysis (Table 2) showed (besides the influence of time) the negative relation between chlorophyll-a, NH_4 and temperature.

No influencing factors besides time could be ascertained for pH (Table 2).

Si, NH_4 and NO_3 show a significant correlation (negative in NH_4 and positive in Si and NO_3) with salinity (Table 2), which itself has decreased drastically in summer during the past years (Fig. 11) in close relation with temperature (Table 2).

DISCUSSION

Up to the mid-seventies, the Wadden Sea of Sylt was an area which was far less eutrophicated than comparable areas in the Dutch Wadden Sea. The Wadden Sea of Sylt had distinct nutrient minima during summer (Hickel, 1989), whereas the Dutch Wadden Sea showed phosphate-maxima during this season (de Jonge & Postma, 1974).

A decade later (1984, 1985), phosphate-concentrations in July–September were

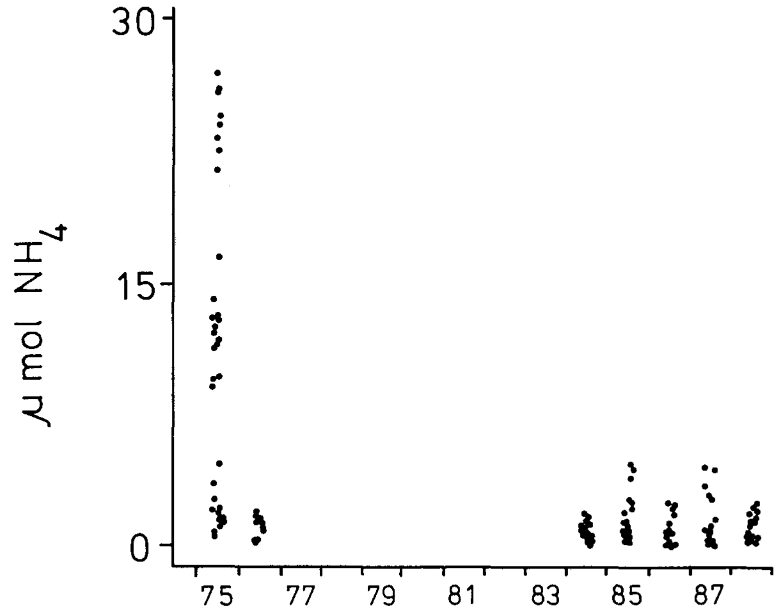

Fig. 8. NH_4 in µgat l^{-1} in different years in summer. X-axis = year. Y-axis = NH_4

Table 1. A = Correlation-coefficient for the relation between time and the different parameters, in brackets probability P. B = Spearman-Rank correlation coefficent for the relation between time and the different parameters, in brackets probability P. C = Partial correlation coefficient for the relation between time and the different parameters; the influence of temperature and salinity excluded; in brackets probability P

Parameter	A	B	C
Chlorophyll-a	0.410 (0.00003)	0.353 (0.0005)	0.355 (<0.001)
pH	0.463 (0.00001)	0.488 (0.0001)	0.265 (0.01)
Salinity	−0.618 (0.00001)	−0.374 (0.0001)	--
Ammonia	−0.410 (0.00001)	−0.522 (0.0001)	−0.511 (<0.001)
Nitrite	0.492 (0.00001)	0.356 (0.0001)	0.346 (<0.001)
Nitrate	0.245 (0.00009)	0.250 (0.0001)	0.319 (<0.001)
Phosphate	0.320 (0.00001)	0.178 (0.0053)	0.196 (<0.001)
Silicate	0.702 (0.00001)	0.633 (0.0001)	0.813 (<0.001)

about four times higher in the Wadden Sea of Sylt, as shown by Hickel (1989) who mentions the possible influence of climatic differences between these years.

An increase of nutrient-concentrations has been shown for the German Bight (Lucht & Gillbricht, 1978; Radach & Berg, 1986), not only for phosphate but also for nitrogen, concomitant with a decrease in salinity (Radach & Berg, 1986) and detectable only during summer. Radach & Berg mentioned a possible influence of rainfall but could not prove this from their data.

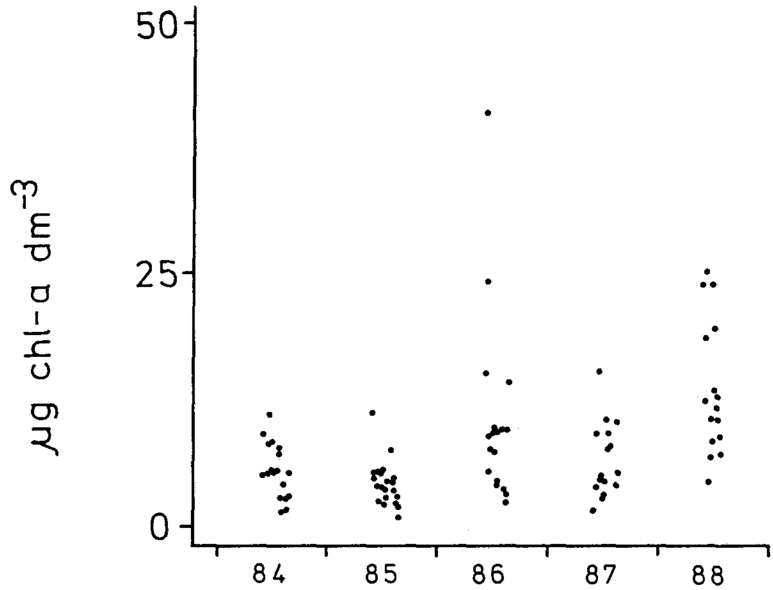

Fig. 9. Chlorophyll-a in µg l^{-1} in different years in summer. X-axis = year. Y-axis = Chlorophyll-a

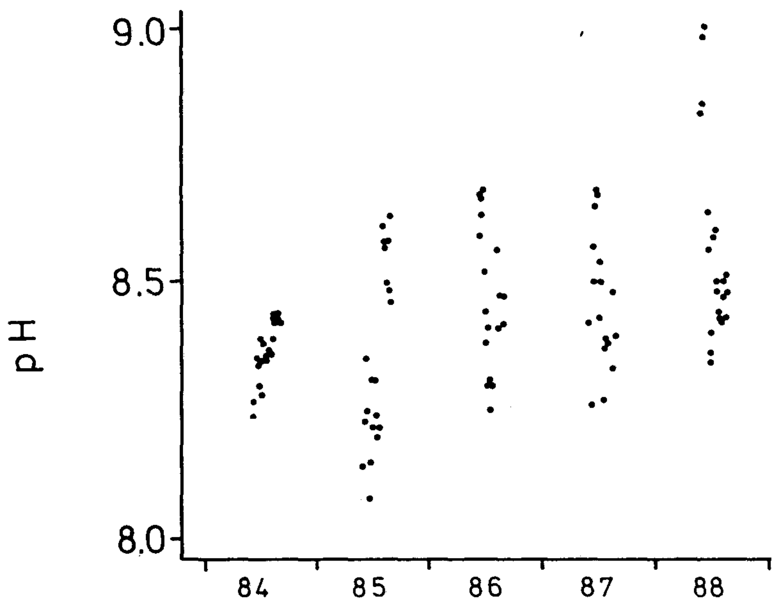

Fig. 10. pH-value in different years in summer. X-axis = year. Y-axis = pH

Table 2. List of parameters of significant influence ($P < 0.05$) on the different parameters measured, derived from a stepwise variable selection. Factor = Parameter of significant influence. t = Regression coefficient/standard error. sl = significance level for the t-value (the probability that a larger absolute t-value would occur if there were no marginal contribution from that parameter)

Parameter	Factor	t	sl
Chlorophyll-a	time	5.294	<0.0001
	temperature	−2.749	0.0072
	ammonia	−3.855	0.0002
pH	time	5.346	<0.0001
Salinity	time	−11.644	<0.0001
	temperature	6.676	<0.0001
Ammonia	time	−9.406	0.0001
	salinity	−3.519	0.0005
	rainfall	3.100	0.0022
Nitrite	time	8.251	<0.0001
	rainfall	2.359	0.0191
Nitrate	time	4.993	<0.0001
	salinity	2.331	0.0206
Phosphate	time	5.119	<0.0001
	temperature	−5.940	<0.0001
Silicate	time	21.780	<0.0001
	temperature	−2.622	0.0093
	salinity	4.185	<0.0001

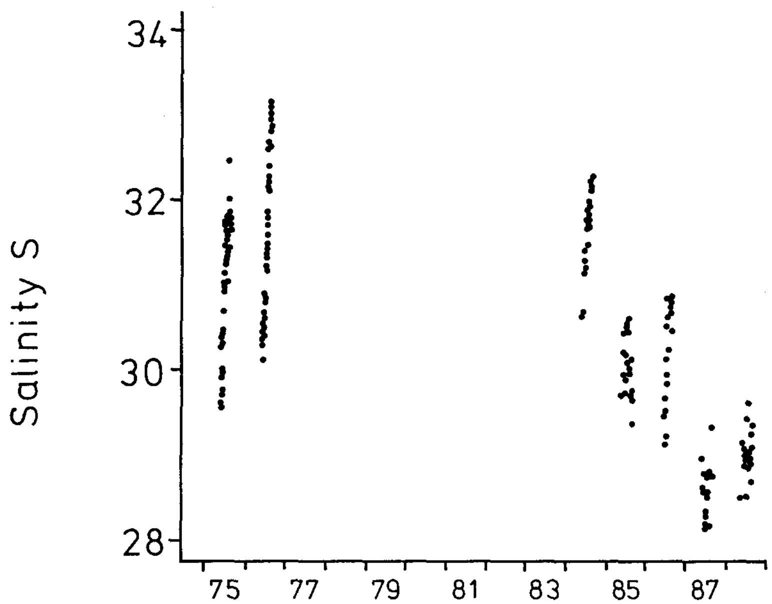

Fig. 11. Salinity S in different years in summer. X-axis = year. Y-axis = Salinity

The magnitude of water exchange between the Wadden Sea of Sylt and the German Bight of about 7 % per tide (Hickel, 1980) makes it rather likely that the increase of nutrients in the German Bight would show up in the Wadden Sea as well. This is shown here for NO_2, NO_3, PO_4 and Si and a significant influence of rainfall could be demonstrated during summer months on nitrogen compounds. There are at least two possible explanations.

Measurements by the "Niedersächsische Landesamt für Wasserwirtschaft" (Rost, 1987) have shown that near the island Norderney rain contains about 80 μgat N l^{-1} (1.6 mg NO_3 and 0.9 mg NH_4). The Wadden Sea of Sylt extends over an area of about 419 km^2. A typical rainy summer can lead to a rainfall of about 20 l $week^{-1}$ m^{-2}, as has been shown by measurements by the "Deutscher Wetterdienst, Wetterstation List". If we assume that rain at Sylt contains as much nitrogen as rain at Norderney, this would lead to a weekly input of 6.7×10^{11} μgat N for the whole area. The volume of the Wadden Sea is about 8.45×10^{11} liters. Thus rainfall is responsible for an increase of about 0.15 μgat N l^{-1} day^{-1}. This is 20 % to 30 % of the actual nitrogen content in summer and may be a possible explanation for the significant correlation between nitrogen and rainfall.

This relation between nitrogen and rainfall was only true for NH_4 and NO_2, not for NO_3 which was positively related to salinity in contrast to the other nitrogen compounds. Presumably, NO_3 enters the Wadden Sea area by tidal water movements; the same holds true for silicate. Radach & Berg (1986) have shown that Elbe discharge has increased significantly over the last 23 years, as has the nitrogen-concentration in the Helgoland Bight.

Hickel has shown that the Elbe has a significant influence on the Wadden Sea of Sylt which is 6 times as high as the influence by local freshwater inflow. Thus, an influence by increased Elbe discharge with its nutrient-load on the Wadden Sea is very likely.

The significant negative correlation between phytoplankton (chlorophyll-a) and NH_4 is thought to reflect the uptake of nitrogen during algal growth; Si- and PO_4-concentrations are too high to be influenced by the small amount of phytoplankton compared to the benthic microflora.

What can clearly be seen from the present paper is the strong variability of the parameters measured within the Wadden Sea area. Only during the season of least variability (summer), could a trend in the concentrations be verified for some parameters. Longer time series are needed to prove trends during other seasons and for other parameters.

On the other hand, it seems somewhat alarming that, even in areas of great natural variability, a positive trend in nutrient concentration could be found.

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