# NUTRIENT SIGNATURES IN THE WADDEN SEA AND ADJACENT TERRESTRIAL AREAS

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## Introduction

Inorganic nutrients in the Wadden Sea are derived from a number of sources including runoff from land, import of organic matter from the coastal North Sea and remineralisation of this material in the Wadden Sea. As pointed out already by POSTMA (1954) for nutrients the Wadden Sea is a net exporting system. In the Lower Saxonian Wadden Sea and especially its East Frisian part rivers do not play a major role in terrestrial input.

## Material and methods

Water samples were taken from 1992 until present at various locations along the Lower Saxonian coast, particularly in the Jade Bay and the backbarrier area of Spiekeroog Island (Figs. 1 and 2). Station 1 in the tidal inlet Otzumer Balje was the most frequently sampled location (Fig. 1). Samples were prescreened over 300 µm plankton gauze und usually filtered using glass fibre filters (Whatman GF/C). The inorganic nutrients, reactive dissolved phosphate (RDP), ammonium, nitrite, nitrate and silicate were determined according to GRASSHOFF *et al.* (1983, 1999) with the modifications suggested by LIEBEZEIT & VELIMIROV (1984). Data for terrestrial samples are corrected for natural background absorption.

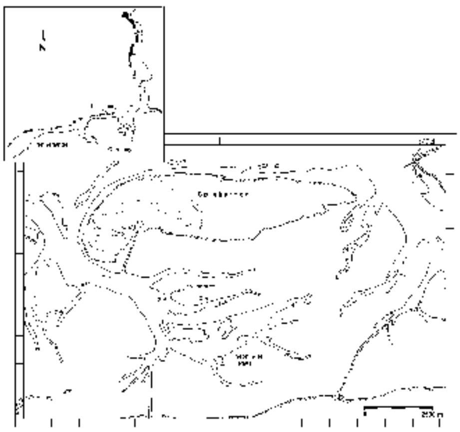

Fig. 1. Sampling stations in the backbarrier area of Spiekeroog Island.

Fig. 2. Sampling stations along the Jade Bay coast. 1 – Wangertief, 2 – Hooksieler Binnentief, 3 – Maade, 4 – Mariensiel, 5 – Dangaster Tief, 7 – Jade.

## Temporal variability

All compounds analysed display variability at various time scales ranging from tidal to annual cycles. Tidal cyclicity is usually not pronounced (Fig. 3). Only in a few cases were maxima at low water and minima at high water observed, which indicate export of dissolved nutrients with the outgoing tide.

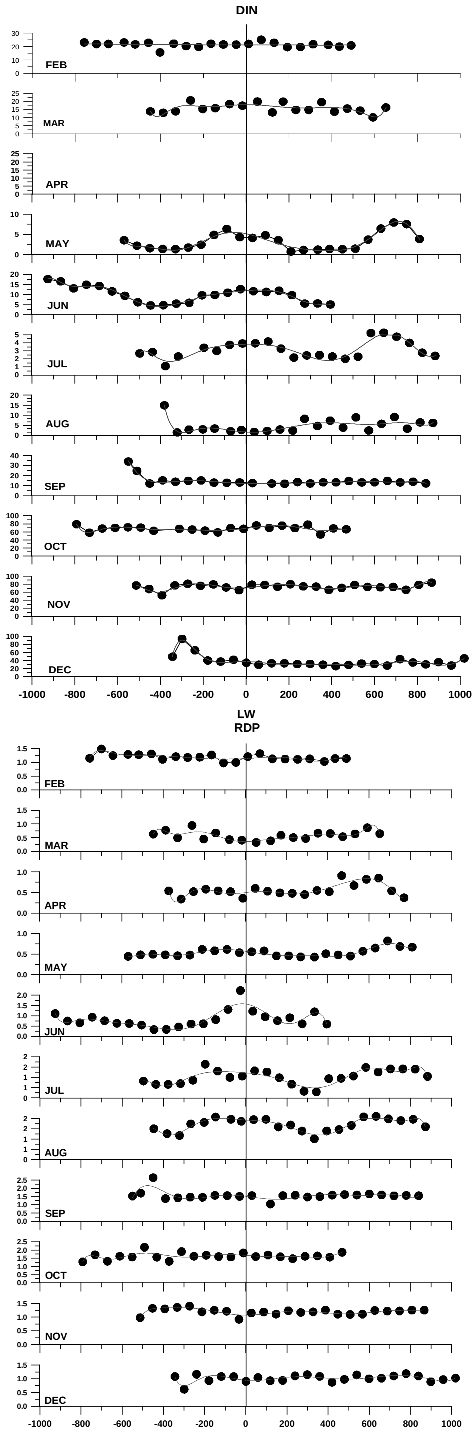


Fig. 3. Tidal cycles of dissolved inorganic nitrogen (top; DIN – sum of nitrite, nitrate and ammonium) and reactive dissolved phosphate (bottom) in 1995 at station 1 in the Spiekeroog area (Fig. 1). LW – low water. Concentrations in µMol/L.

The inorganic nitrogen compounds are dominated by ammonium, especially in summer (Fig. 4) which is in line with the high remineralisation activity of the Wadden Sea heterotrophic communities. Nitrite as intermediate product in the oxidation of organic matter also has relatively high concentrations. These data corroborate earlier findings of KALLE (1956) who showed the Wadden Sea to export nitrite, the intermediate compound in the organic matter oxidation with nitrate as the final product, into the coastal North Sea.

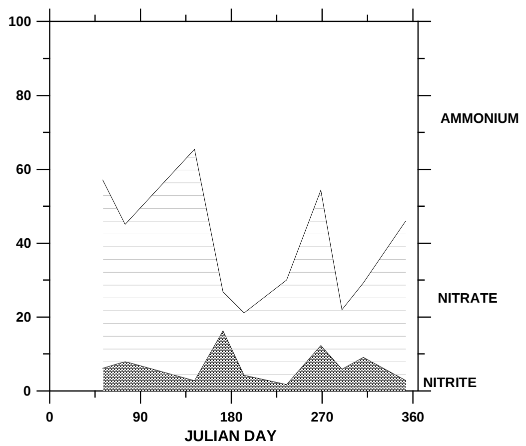


Fig. 4. Relative contributions of ammonium, nitrite and nitrate to the inorganic nitrogen pool in 1995.

Data from 1994 to 2002 show that the overall annual cycle is largely controlled by biological activity (Fig. 5). As a result of both benthic and pelagic primary production summer values are low but show no nutrient depletion. Differences between the individual years are not pronounced.

Early winter values are high and decrease until spring indicating export of dissolved nutrients. This also suggests that the pool of degradable organic matter in the Wadden Sea is not to a large extent replenished from terrestrial sources despite the fact that at times of high rainfall and hence high runoff, i. e. in late autumn and winter, input from land sources is high.

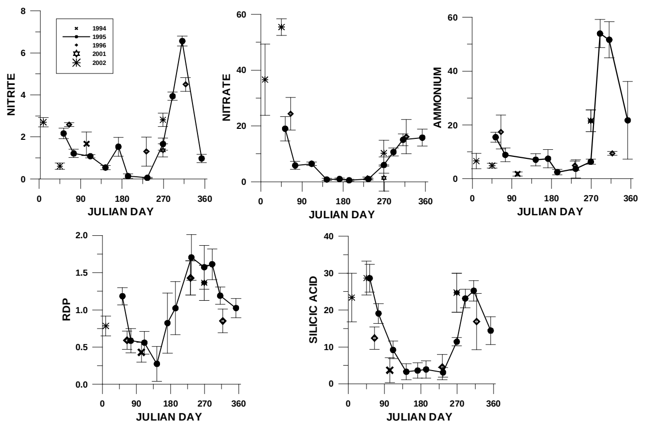


Fig. 5. Annual cycle (1994 – 2002) of inorganic nutrients at station 1 in the Otzumer Balje (Fig. 1). Mean values in µMol/L and 1 SD are shown.

Reactive phosphate increases already in early summer as a result of the thinning of the oxic sediment layer due to increased benthic oxygen consumption at higher temperatures. This reduces the phosphate trapping capacity of the iron(III) oxohydroxide (DE JONGE & POSTMA, 1974).

The high ammonium values in October and November 1995 are noteworthy. As in other years winter values are lower, these high concentrations are presumably due to a yet unidentified additional input of this nutrient. In this context it is worth mentioning that in November 2002 low oxygen saturation values (minimum value ~40%) were determined in the backbarrier area of Langeoog Island further to the west of the Otzumer Balje (G. FLÖSER, pers. commun., 2003). This points to a direct input of easily degradable organic matter which in turn could lead to high ammonium contents. On the other hand, in a less sheltered location in the Jade Bay a higher interannual variability is seen (Fig. 6). This may be due to higher energy or to the fact that the main freshwater discharge point, the Wangersiel flood gate, is located N of the sampling point (station 1 in Fig. 2).

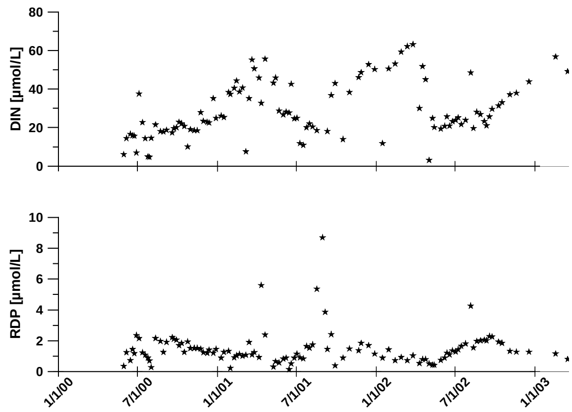


Fig. 6. Dissolved inorganic nitrogen and reactive phosphate from May 2000 to February 2003 at the NWO terminal in the outer Jade Bay.

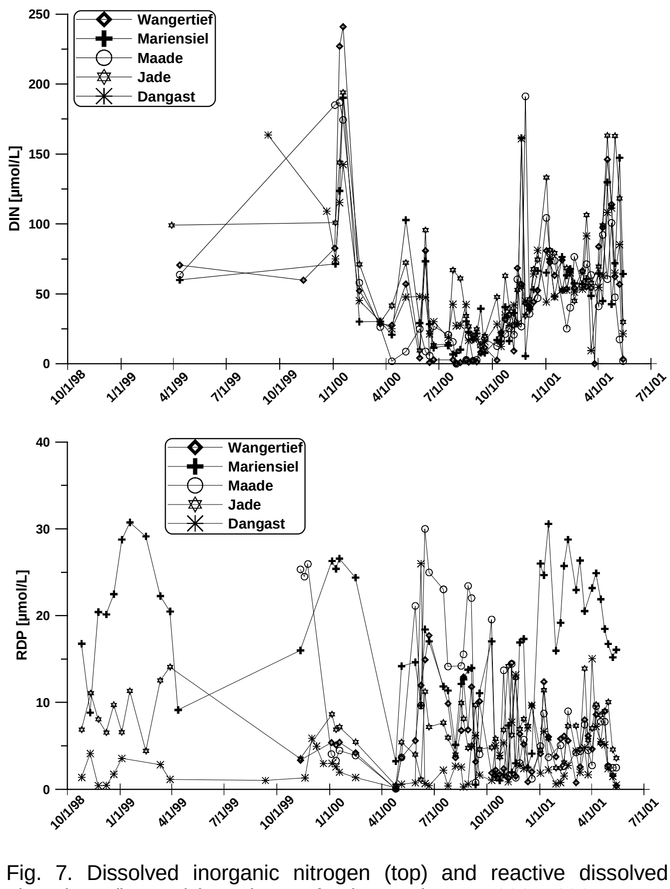


Fig. 7. Dissolved inorganic nitrogen (top) and reactive dissolved phosphate (bottom) in Jade Bay freshwater inputs 1998 – 2001.

Thus, this discharge will be transported with the incoming flood tide to the NWO terminal. In addition both the Hooksiel and Maade discharges (stations 2 and 3 in Fig. 2) may influence the situation at the terminal.

Nutrient analysis in Jade Bay freshwater sources indicates pronounced variability between individual years and sources

(Fig. 7). This is presumably due to the amount of rainfall, i. e., runoff, and possibly also to actual agricultural practise, e. g. fertiliser usage.

In contrast to the Wadden Sea annual cycle, there is no clear seasonality in the phosphate time course at the five freshwater sources of the Jade Bay although for some locations, e. g. Mariensiel, higher winter values were observed.

On the other hand, dissolved inorganic nitrogen shows a strong covariation at all five stations from 1999 to 2001. Nitrogen compounds are easily soluble and hence they will be leached by rain from any type of soil. Phosphate, on the other hand, binds more or less strongly to soil minerals, and the leaching efficiency will hence depend on the soil type.

In contrast, freshwater stations sampled in the drainage area of the Neuharlingersiel deep which discharges into the Spiekeroog backbarrier area show pronounced seasonality, i. e. high winter and low summer values (KÖLSCH *et al.,* this volume).

This suggests that besides biological activity other factors as mentioned above have to be taken into account for an explanation of nutrient annual cycles in freshwater sources.

## Import and export of nutrients

A comparison of high and low water concentrations at station 1 (Fig. 1) shows that reactive dissolved phospate and silicate are exported regularly into the coastal North Sea whereas nitrogen imports and exports are more or less balanced (Fig. 8).

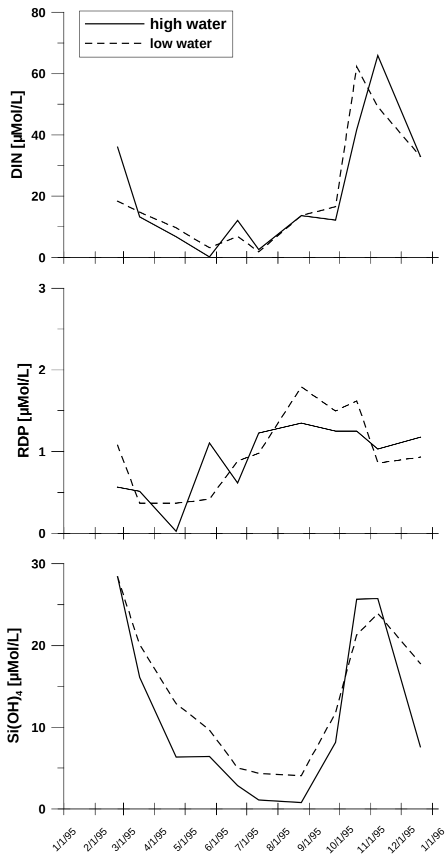


Fig. 8. Comparison of high and low water nutrient concentrations for station 1 (Otzumer Balje) for 1995.

## Redfield ratios

The Redfield ratio, i. e. C:N:P=106:16:1, usually describes the elemental composition of phytoplankton and also the remineralisation of this organic material in a first approximation. Usually, this ratio varies between about 1:10 and 1:20.

In the Spiekeroog Wadden Sea station 1 in summer 1995 an excess of reactive phosphate occurs as a result of early liberation of this compound from the sediment as discussed above (Fig. 9). This also holds for the Jade Bay station (Fig. 10). Winter values, on the other hand, show a distinct surplus of nitrogen. This may be either due to higher oxidation rates at this time of the year or to higher N input from land, e. g. as a result of the application of liquid manure by farmers.

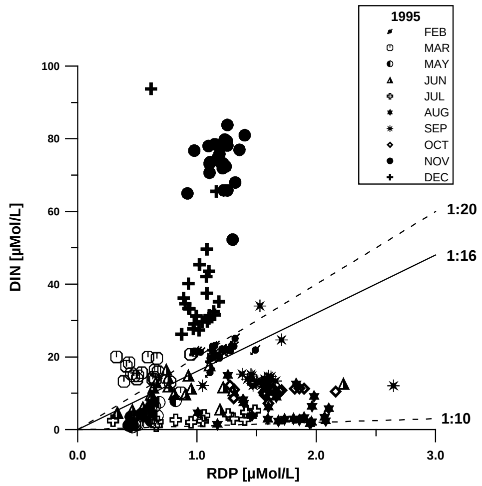


Fig. 9. Dissolved inorganic nitrogen *versus* reactive dissolved phosphate for Wadden Sea samples.

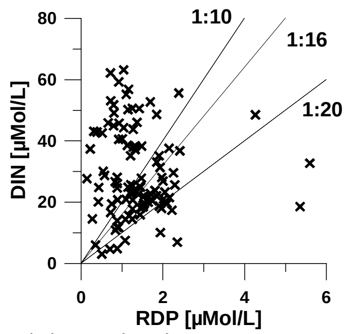


Fig. 10. Dissolved inorganic nitrogen *versus* reactive dissolved phosphate for Jade Bay samples (Fig. 6).

On the other hand, freshwater data show that in most cases inputs conform to the Redfield with the exception of the Kortenhörn location (Fig. 11). This exhibits a marked nitrogen excess. Wangertief samples show an excess of phosphate especially in summer.

This, however, does not necessarily have a direct influence on nutrient concentrations in the Wadden Sea. As flow and discharge data for the sampling locations in the drainage area of the Neuharlingersiel deep are not available the relative contribution of individual stations to the total discharge cannot be ascertained at present.

## Controlling factors

Besides biological activity, i. e. primary production and remineralisation, other factors appear to influence nutrient concentrations in the Wadden Sea. One is certainly energy input. High wind velocities lead to higher waves which in turn influence porewater exchange. Wave pumping effects were described by RUTGERS VAN DER LOEFF (1981).

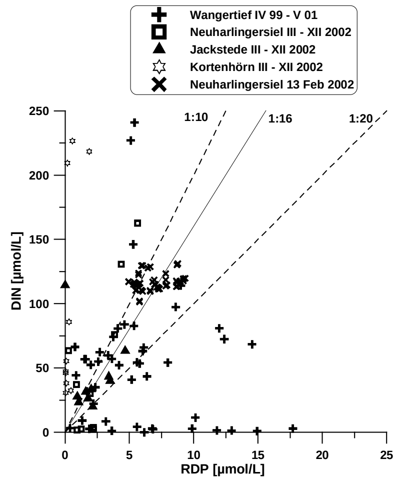


Fig. 11. Dissolved inorganic nitrogen *versus* reactive dissolved phosphate for freshwater sources.

At the Spiekeroog station relative standard deviations are highest in summer (Fig. 12) pointing to marked low/high water concentration differences as a result of biological activity (Fig. 7). At this time of the year they vary without any relation to external physical forcing. In winter, however, there is a relation between the relative standard deviation and wind velocity (Fig. 13). This suggests that wind strength, as mentioned above, also may influence nutrient concentrations.

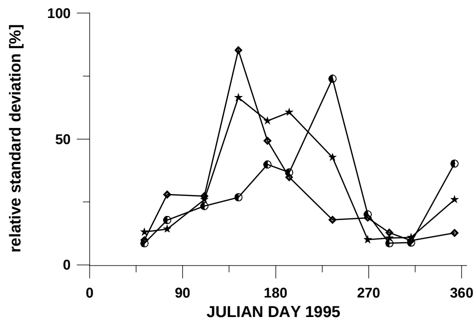


Fig. 12. Relative standard deviations for reactive phosphate, dissolved inorganic nitrogen and silicate for 1995, station 1 in the Otzumer Balje (Fig. 1).

## Conclusions

The data obtained so far suggest that inorganic nutrient concentrations in the Wadden Sea and in its freshwater sources are controlled by a number of variables. These include both autotrophic and heterotrophic biological activities as well as physical forcing. In addition, runoff and agricultural practise has to be taken into account. Furthermore, especially for the inorganic nitrogen compounds atmospheric inputs need to be considered as well.

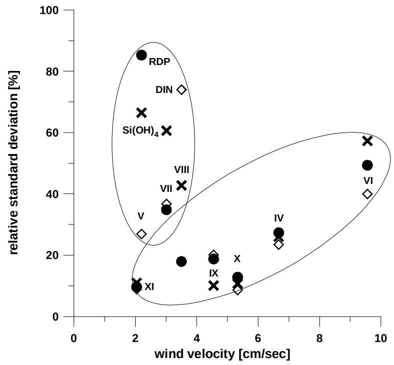


Fig. 13. Relation between relative standard deviation and wind velocity for data set of Fig. 10.

Although nutrient data indicate a dominant biological control in the absence of information on both primary production and heterotrophic activity this link is at present only circumstantial. Another parameter influencing nutrient concentrations is the amount and nature of the organic material present in Wadden Sea waters. Hence, for a comprehensive interpretation of nutrient data more background information is needed.

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