Götz Flöser, GKSS
Geesthacht, FRG

Nutrient Gradients in the East Frisian Wadden Sea

The EU water framework directive aims at the reduction of eutrophication of inland and coastal waters in the European countries. Human influence (fertilisation, domestic and industrial sewage) has increased nutrient input into coastal waters. Consequently, the high nutrient levels must be reduced to a value slightly above the "natural level", i.e. the nutrient level without human influence. The according nutrient concentration is called background concentration.

One difficulty in the definition of the background values is that these values are assumed to be more or less homogeneous within the Wadden Sea. This assumption, however, does not reflect the true nutrient conditions in the Wadden Sea.

Nutrient budget calculations in the Wadden Sea are usually derived in the following way: The Wadden Sea is, similar to the procedure used in the North Sea ecosystem model ERSEM, divided into several compartments. The water exchange between these boxes is calculated using hydrodynamic models. At stations along the dividing lines of the compartments or near the tidal inlets, time series of nutrient concentrations are taken (Philippart et al., 2000; Dick et al., 1999). Nutrient transport between the compartments can then be calculated by multiplying water flux and nutrient concentration.

This method relies on two assumptions: 1) the water exchange mechanism is well understood and 2) nutrient concentrations are homogeneous within the compartments.

Assumption 1: Hydrodynamics

The hydrodynamic models are quite well able to reproduce the water transport within the shallow Wadden Sea. A comparison between water level measurements between the East Frisian Islands Langeoog and Baltrum and the results of a hydrodynamic model produced satisfactory results (Stanev et al., 2003), so that the first assumption can be agreed to.

Assumption 2: Homogeneous nutrient concentration

The second assumption, however, has not yet been investigated in detail. In Germany, nutrient concentrations are routinely measured on a weekly basis by authorities of the States at several stations within the Wadden Sea, e.g. on Norderney and Sylt, but not spatially resolved.

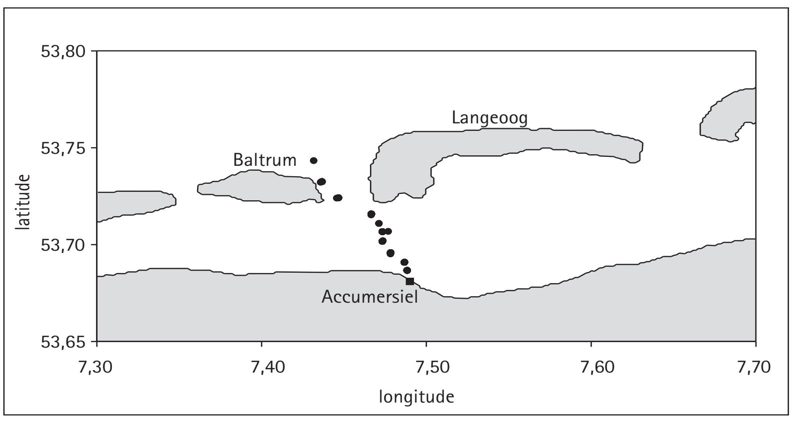
Differences Between the Wadden Sea Regions

Nutrient gradients, i.e. spatially resolved nutrient concentrations within the Wadden Sea, were measured during the large German research projects KUSTOS and TRANSWATT. These projects concentrated on the North Frisian Wadden Sea, i.e. the west side of Schleswig-Holstein (van Beusekom 1999).

The main difficulty here is the combined influence of the rivers Elbe and Weser. Under normal (= westerly) wind conditions, the permanent counter clockwise residual current in the North Sea carries the river water into the North Frisian Wadden Sea. This influence is, of course, dependent on the river runoff, and is easily detectable via water salinity. The usually high nutrient load of river water covers, however, the weaker signal arising probably from the Wadden Sea itself. Thus, the final report of the projects could only state the dependence of the Wadden Sea nutrient situation on the Elbe and Weser load and on the weaker signals from the direct runoff from the mainland.

In the intensively studied Western Dutch Wadden Sea, there is also a permanent freshwater source: the IJsselmeer runoff which is about as large as that of the river Weser. This source creates a permanent salinity gradient from the IJsselmeer sluices to the tidal inlets which is connected to a nutrient concentration gradient (Zimmermann 1976).

Figure 1: East Frisian Islands Baltrum and Langeoog.



In order to extract the specific Wadden Sea signal, we decided to measure nutrient concentrations in the narrow East Frisian Wadden Sea (Fig. 1). There is no direct freshwater influence except the sluice runoff as can be seen from salinity measurements. During the year 2003, 27 cross-shore profiles were taken from the tidal inlet to a position close to the little port of Accumersiel. Results from nutrient measurements are shown in Fig. 2.

Elevated Nutrient Concentrations Near the Mainland

The nutrient situation is clearly different in summer and in winter. In winter, precipitation is high, and the nutrient load from mainland ponds is, mainly due to the use of fertilisers, high as well. Biological production is low, and the water masses released from the sluices into the Wadden Sea are transported into the coastal water without being consumed by primary production. This can be demonstrated by the linear increase of nutrient concentration and a high correlation with salinity (Fig. 3). The transport mechanism is the permanent mixing of coastal water with the Wadden Sea water through the tidal currents. The linear correlation suggests a mixing of sluice water (DIN around 250 µmol/L, salinity 0) with Wadden Sea water (DIN 30 µmol/L, salinty 32 ‰).

In the summer months, nutrient concentrations are much lower, a well known phenomenon that is due to high biological production and thus consumption of nutrients. A second observation is that steep gradients in the northern direction evolve (Fig. 2) close to the coast. These gradients arise in May with the beginning biological activity and disappear in October. There is essentially no correlation with salinity (Fig. 3), in contrast to the winter values.

Where Do the Nutrients Come From?

As to the origin of the elevated summer nutrient concentrations near the mainland, we must keep in mind that there is no permanent freshwater influence inside the East Frisian Wadden Sea like the IJsselmeer or the Elbe River. The sluice inputs (released water and nutrient concentrations) are also very low. Thus, the gradient's origin must lie in the Wadden Sea itself. A nutrient source is the decomposition of organic material in sediment and suspended matter in the waters of the Wadden Sea and the subsequent release of dissolved nutrients into the water phase. This assumption alone, however, would lead to a uniform high nutrient concentration in the back barrier region and not to a gradient inside the Wadden Sea.

There are two processes that can lead to a profile like the observed one: An increasing nutrient production towards the coast and a decreasing diffusion coefficient.

1) The sediment's grain size decreases towards the mainland, a consequence of the decreasing tidal current velocities. The organic matter content along with nutrient production increases in the same direction (Krögel et al., 1998). So we can safely assume that the production of dissolved nutrients, as a result of the decomposition of organic matter, increases towards the mainland.

2) Turbulent diffusion, the main mixing mechanism in the Wadden Sea waters, depends on current velocity and water depth. Since the current velocity decreases towards the mainland, the diffusion will decrease also. Ebenhöh et al. (2004) have demonstrated that this process alone can generate nutrient gradients.

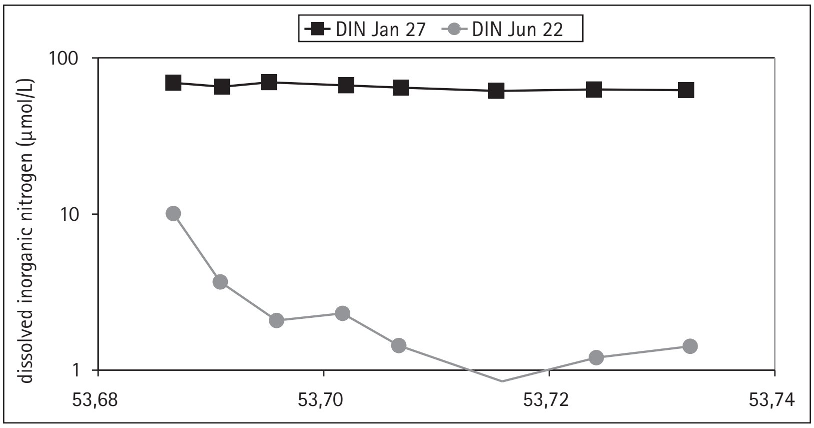
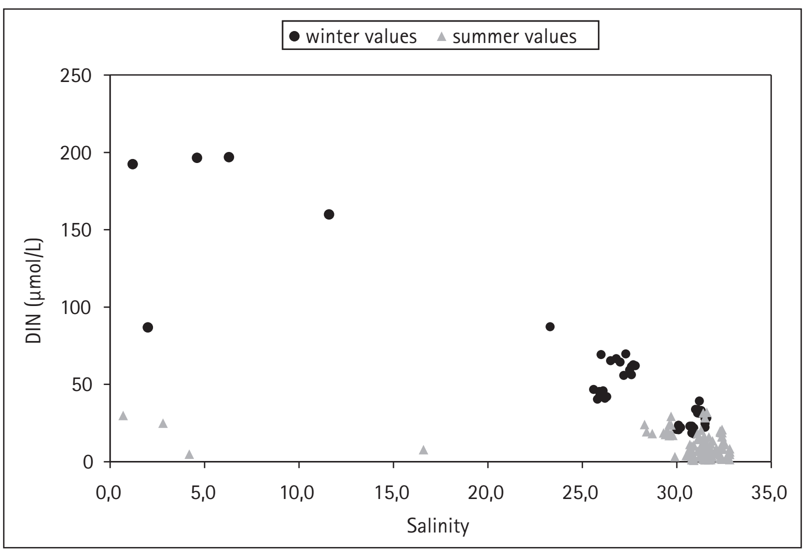


Figure 2: Nutrient gradients in the Wadden Sea in January and June 2003. X-axis is the latitude. Note the logarithmic concentration scale!

Figure 3: Dissolved inorganic nitrogen vs. salinity, summer and winter 2003.



Conclusion

The nutrient concentrations in the East Frisian Wadden Sea are not uniform over space and time. In winter, higher nutrient concentrations from the sluice outlets are transported into the North Sea without being consumed by primary production. The production of nutrients by decomposition of organic matter is low as well.

In summer, concentrations of dissolved nutrients are generally much lower due to the consumption by high biological productivity, but steep gradients evolve towards the mainland. These gradients are stable and can be observed from May to October.

There are two processes that can generate these gradients of dissolved nutrient concentrations: 1) elevated nutrient production due to decreasing grain size and thus higher decomposition rate of organic matter and 2) lower diffusion in the water phase due to lower current velocity and water depth.

The combination of these effects can lead to a steeply increasing nutrient concentration towards the mainland. If this working hypothesis is correct, the observed gradients are natural ones and should be considered when doing budget calculations.

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Götz Flöser
Institut für Küstenforschung
GKSS Forschungszentrum
Max-Planck-Straße 1
D - 21502 Geesthacht
floeser@gkss.de