Eutrophication of the Wadden Sea

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The three Wadden Sea countries sponsored a project in which Eutrophication criteria for the Wadden Sea were investigated. As part of this project, time series on nutrients in the Wadden Sea have been analyzed. Evidence was compiled that shows that the amount of nitrogen imported into the North Sea determines the amount of organic matter produced by phytoplankton within the North Sea. Part of this organic matter is imported into the Wadden Sea. The nutrients released after degradation of this organic matter support the local productivity. In wet years with a high nitrogen load via rivers, more organic matter is remineralised in the Wadden Sea and - at least in the Western Dutch Wadden Sea - more phytoplankton is present than in dry years with a low nitrogen load.

Introduction

Recent problems like the occurrence of "Black Spots", the increased blooms of *Phaeocystis*, increased primary production or the decline of eelgrass all have been related to the eutrophication of the Wadden Sea. There is no doubt about the essential role of increased nutrient input in the Wadden Sea eutrophication. However, it is still under discussion which nutrients are mainly responsible and how these nutrients are transported into the Wadden Sea. For instance, nutrient input via the IJsselmeer, via the river Rhine and coastal zone or nutrient input through the import of organic matter from the North Sea have been all been mentioned as possible eutrophication pathways. Both phosphorus and nitrogen were suggested to be the limiting nutrient.

Before 1990, a good correlation between phosphorus loads into the Western Dutch Wadden Sea and primary production was found (de Jonge, 1990). This suggested phosphorus to be the key element. But despite declining phosphorus loads since the mid-eighties the primary production remained high. Since the nitrogen loads have remained high this nutrient was also suggested to be the key element in the Wadden Sea eutrophication (Cadée & Hegeman, 1993).

In 1996, a study was started with the aim of developing "Wadden Sea Specific Eutrophication Criteria" based on decisions of the 7th Trilateral Governmental Wadden Sea Conference in 1994. The three Wadden Sea countries agreed upon a catalogue of common Targets for the protection of the Wadden Sea Cooperation Area. With regard to eutrophication, the Target "to achieve a Wadden Sea which can be regarded as a eutrophication non-problem area" was defined. The rationale for this specific formulation can be found in developments in the framework of the Oslo and Paris Convention (OSPAR). Here, work was going on aiming at defining the OSPAR Convention area in terms of eutrophication problem, potential problem and non-problem areas. In order to be able to evaluate the Wadden Sea eutrophication Target, the development of Wadden Sea specific criteria was necessary.

The project was sponsered by the three Wadden Sea countries and coordinated by the Common Wadden Sea Secretariat. As part of the project long-term data on nutrients in the Wadden Sea were analyzed. One of the goals was to investigate whether long term changes in the dynamics of the seasonal cycle of nutrients could give information on the eutrophication status of the Wadden Sea. Such characteristics could also be used to distinguish between more and less eutrophied Wadden Sea areas. In this paper, we will highlight some of the characteristics of the nutrient cycles in the Wadden Sea and the factors that determine their interannual variability. Our focus will be on Dutch Wadden Sea data.

Conceptual Model

The basis for our data analsysis was the conceptual model shown in Figure 1. This model dynamically links via two steps nutrient input via rivers with the nutrient cycle in the Wadden Sea. These steps are:

1. The amount of nutrients imported into the coastal zone determine the magnitude of the primary production in the coastal zone.
2. A proportional part of the organic matter produced in the coastal zone is imported into the Wadden Sea.

Within the Wadden Sea, the imported organic matter is degraded by bacteria and small animals. The nutrients that are released during this process can than support the local primary production. The amount of nutrients discharged by rivers into the coastal zone strongly depends on the amount of water discharged. Our conceptual model predicts that in wet years with a high nutrient load more organic matter can be produced in the coastal zone and more organic matter can be imported into the Wadden Sea than in dry years with a low nutrient load.

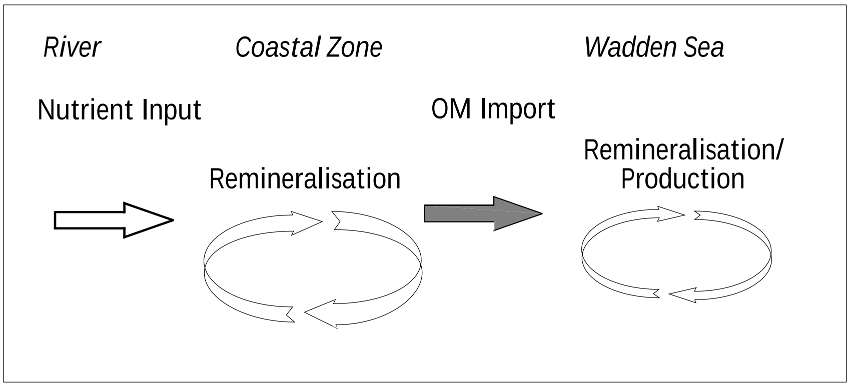


Figure 1
A conceptual model of nutrient and organic matter flow between rivers, the coastal zone and the Wadden Sea.

Nitrogen Limits the Primary Production

Evidence exists that nitrogen limits primary production in the central parts of the North Sea. Recently, its was shown that also in the coastal zone adjacent to the Wadden Sea the amount of nitrogen available to the phytoplankton determines the annual primary production (Hydes et al., 1999; van Beusekom et al., submitted). This indicates a higher primary production in years with a high nitrogen load.

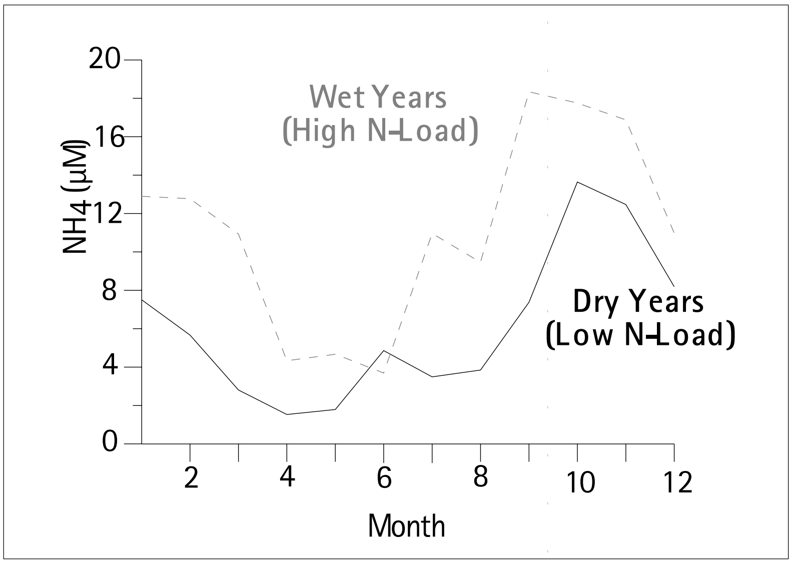
The Wadden Sea Imports Organic Matter

The importance of organic matter import for the Wadden Sea was already pointed out by Verwey and Postma. Since then, many studies have focussed on the carbon cycle in the Wadden Sea. A review of available carbon budgets shows that at present each year about 100 g C m^{-2} are imported from the North Sea into Wadden Sea (van Beusekom et al., submitted). This is about one third of the annual primary production within the Wadden Sea. The organic matter import from the North Sea into the Western Dutch Wadden Sea and into the Sylt Rømø Bight are of the same magnitude.

Interannual Variability: the Difference Between Wet and Dry Years

In the previous paragraphs we compiled evidence that the nitrogen import into the coastal zone determines the off shore annual primary production. Also, it was shown that part of the produced organic matter is imported into the Wadden Sea. This underlines the feasibility of our conceptual model. Because of the large uncertainties inherent to carbon budgets (not to speak of the enormous effort it takes to carry out the necessary measurements), such budgets are not suitable for investigating interannual variability. We used Dutch monitoring data to investigate whether a relation exists between nitrogen input into the coastal zone and the nutrient cycles related to organic matter import within the Wadden Sea. As a measure for the organic matter import, we used ammonium and nitrite. These nitrogen compounds are released during the degradation of organic matter. Here, we will focus on ammonium. During summer ammonium concentrations are low because phytoplankton and phytobenthos take up all the ammonium released from organic matter. But during autumn, the worsening light conditions prevent algal growth whereas degradation of organic matter continuous and an autumn maximum of ammonium can build up. In a statistical analysis, we could show a significant correlation between riverine nitrogen loads and the remineralisation intensity in autumn. Figure 2 exemplifies this relation: In wet years with a high nitrogen load, more ammonium is found in autumn than in dry years with a low nitrogen load. Apparently a direct relation exists between the nitrogen

Figure 2
A comparison of the seasonal cycle of ammonium in the Western Dutch Wadden Sea in dry years with a low riverine nitrogen load and wet years with a high riverine nitrogen load. Data: Rijkswaterstaat, NL



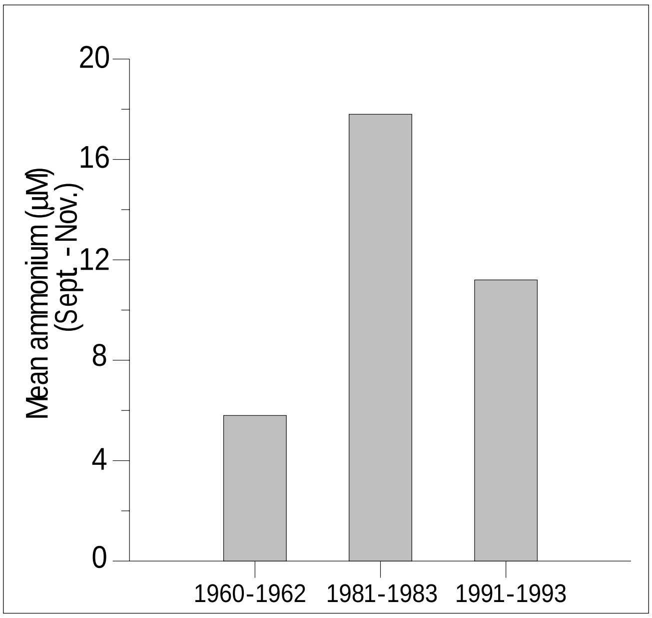


Figure 3
A comparison of ammonium in autumn in the Western Dutch Wadden Sea during 1960 - 1962, 1981 - 1983 and 1991 - 1993. Data: Postma (1966) and Rijkswaterstaat, NL.

load into the coastal zone, productivity in the coastal zone and the amount of organic matter imported and degraded in the Wadden Sea.

A Look at the Sixties

First measurements of the nitrogen seasonal cycle in the Wadden Sea were carried out by Postma (1966). A comparsion of his autumn data with those from the wet early 1980s and dry early 1990s shows that the ammonium concentrations and therefore the remineralization intensity has increased by a factor of two to three during the past four decades (Fig. 3).

Résumé

The analysis of literature and monitoring data shows that nitrogen determines the production of organic matter in the coastal zone. Part of this organic matter is imported into and degraded within the Wadden Sea, where it supports the high local productivity. However, we could not find a similarly clear relation between the riverine nitrogen load and eutrophication related problems like *Phaeocystis* blooms, "Black Spots" or mass occurrences of green algae. This underlines that the Wadden Sea reacts in a very complex way to the increased eutrophication.

References

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