National Environmental Research Institute
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Monitoring and Assessment in the Wadden Sea

Proceedings from the 11. Scientific Wadden Sea Symposium
Esbjerg, Denmark, 4.-8. April 2005

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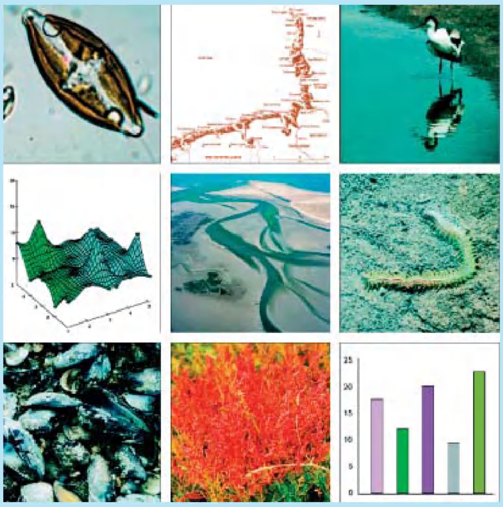

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Karsten Laursen (Ed.)

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National Environmental Research Institute

Foreword

The 11. International Scientific Wadden Sea Symposium, held from 4. – 8. April 2005 in Esbjerg, Denmark, brought together more than 150 scientists and policy makers. The symposium was organised by The National Environmental Research Institute, Dept. of Wildlife Ecology and Biodiversity in cooperation with the Common Wadden Sea Secretariat. The focus of the conference was 'monitoring', and under this heading, the existing TMAP (Trilateral Monitoring and Assessment Program), methodologies, experiences from the existing monitoring programs and results of new monitoring methods were the subject to scientific assessment. However, more policy related aspects were also addressed especially in relation to the EU-Directives (Habitats Directive, EU-birds Directive and the Water Framework Directive).
By focusing on the 'monitoring' theme, the symposium provided substantial input into the decision-making associated with the future development of the TMAP by the Trilateral Governmental Conference held in November 2005 on Schiermonnikoog. To this conference the symposium adapted a set of recommendations, which is available on the homepage of the Common Wadden Sea Secretariat: http://www.waddensea-secretariat.org/news/symposia/Esbjerg2005/Esbjerg-2005.html
The symposium was prepared and organized by a scientific committee representing a broad spectrum of scientist and administrators with many years of experiences from the Wadden Sea. The members of the scientific committee were: Peder Agger, Justus van Beusekom, Lillian van der Bijl, Bruno Ens, Kurt Thomas Jensen, Adolf Kellermann, Ingrid Kröncke, Harald Marencic, Wim Wiersinga, Wim Wolf and Karsten Laursen. The latter chaired the committee, organized the symposium and edited the proceedings in cooperation with the members of scientific committee, who refereed the papers assisted by Joop Bakker and Kees Koffijberg. Wim Wolf chaired the recommendation session and edited them in cooperation with Karel Essink. I am deeply grateful for the large effort from all these persons for preparing and carrying out the symposium.

Svend Bichel
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Effectiveness of the Wild Birds and Habitats Directives in the Wadden Sea area: will the tiger lose its teeth?

Jonathan Verschuuren

Jonathan Verschuuren, J. 2006: Effectiveness of the Wild Birds and Habitat Directives in the Wadden Sea area: will the tiger loose its teeth? In: Monitoring and Assessment in the Wadden Sea. Proceedings from the 11. Scientific Wadden Sea Symposium, Esbjerg, Denmark 4. – 8. April, 2005 (Laursen, K. Ed.). NERI Technical Report No. 573, pp. 7-12.

Almost the entire Wadden Sea area has been designated by Denmark, Germany and the Netherlands as a Special Protection Area under the Wild Birds Directive and as a Special Area of Conservation under the Habitats Directive. The new Water Framework Directive will, eventually, also have consequences for the area. What are the consequences of EU Directives aimed at protecting the Wadden Sea area? Provide these Directives effective protection against harmful activities? These questions have been dealt with through a case study on the decision-making process with regard to mechanical cockle fisheries in the Dutch part of the Wadden Sea in 2004. Also, data obtained from other European research projects into the effectiveness of the Directives have been analyzed. These studies indicate that especially the Wild Birds and Habitats Directives can be very effective tools for legal protection of the area. Especially case law by the European Court of Justice has rendered the Directives strong teeth. The Directives offer opportunities to protect the area, without neglecting economic interests, although the effectiveness still very much depends on the political will to take the Directives seriously, and/or on NGOs that go to court, invoking the provisions of the Directives. According to some, the Directives are too effective! Evaluation and amendments of the Wild Birds and Habitats Directives are to be expected within the next few years. The tiger may lose its teeth in this process.

Key words: law, Birds Directive, Habitats Directive, precautionary principle, case law

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Introduction

In this paper the consequences of EU-law for the protection of the Wadden Sea will be analysed. Quite a large number of Directives and Regulations apply to this area, legislation in the field of fisheries and the environment. Pieces of environmental legislation that apply to decision-making processes concerning the Wadden Sea for instance are a large variety of water related directives, nature conservation directives and general environmental law directives, such as the directive on Environmental Impact Assessment (Directive 85/337/EEC as amended by Directive 97/11/EC). Instead of giving a broad overview of all of these pieces of legislation, I decided to focus on the Wild Birds Directive (Directive 79/409/EEC) and the Habitats Directive (Directive 92/43/EEC), since it is beyond any doubt that these directives have a massive impact on decision-making concerning the Wadden Sea area. Over the past seven years I have researched the consequences of these directives on national environmental law by studying case law and legislation, not just in the Netherlands, but also in other EU member states, and I can only conclude that in all member states, conservation law has much improved, resulting in a far better legal protection of both important habitat types and individual species (Bastmeijer et al. 2001, Verschuuren 2002, Verschuuren 2003a, Verschuuren 2004a). Unfortunately, some dark clouds start to appear at the horizon. I will come back to that below.

In 2004, the European Court of Justice (ECJ) rendered a landmark decision on the Habitats Directive in a Wadden Sea case (ECJ 7 September 2004, case C-127/02, Landelijke Vereniging tot Behoud van de Waddenzee and Nederlandse Vereniging tot Bescherming van Vogels v Staatssecretaris van Landbouw, Natuurbeheer en Visserij. Also: Gellermann 2004, Verschuuren 2005). As a consequence, all environmental lawyers in the entire EU now know much about the Wadden Sea area in general and about cockle fisheries in particular. It was a Dutch case in which the court was asked, by the Dutch highest administrative court, to explain important provisions of the Habitats Directive. I will use that case to explain the consequences of the Habitats Directive on decisions concerning activities that may be harmful to protected areas, either under the Wild Birds or the Habitats Directive (the same legal regime applies to both types of areas).

Material and methods

Law and legislation have been studied and analysed over the past few years. The main focus has been on Dutch law. The reason for that focus is the available material, i.e., the number of relevant court cases. In the Netherlands, the number of cases in which courts tested decisions against the Wild Birds and Habitats Directives is enormous, compared to other EU Member States, including Denmark and, to a lesser extent, Germany. Research has shown that in environmental law in general, the overall number of cases in the Netherlands is much higher than in other EU Member States (De Sadeleer et al. 2005). The same appears to be true for Wild Birds and Habitats Directive cases (Backes et al., forthcoming).

The case study focuses on the shellfish fisheries in the Dutch part of the Wadden Sea. The results of this research as well as research into the new landmark case of the ECJ forms the basis of this paper. This case on the Wadden Sea is relevant for all three Member States concerned. It may be an impetus for the three states to harmonize their laws and policies with regard to the implementation of both Directives in the Wadden Sea area. Laws and policies in the three states, including those with regard to Article 6 of the Habitats Directive, the important provision that forms the central subject of this paper, are now inconsistent (Oxford Brookes University 2003).

Results

The applicable legal regime: Article 6

Decision-making on the construction or extension of roads, railroads, ports or airfields, on building permits for houses or environmental permits for industry, or on other projects in areas designated under the Birds Directive or the Habitats Directive is largely regulated by Article 6(3) and 6(4) of the Habitats Directive. These provisions state that plans or projects likely to have a significant effect on a protected area can only go ahead after an assessment has shown that there are no negative consequences. When damage occurs (according to the assessment), the project can only proceed when some extremely strict requirements for exemption have been met. These have been laid down in section 4 and are threefold: a) there may not be an alternative to achieve the goal of the project, b) there have to be overriding public interests at stake, c) compensatory measures have to be taken (and in some cases the European Commission has to grant permission). Bearing in mind that the Birds Directive came into effect in 1981 with a provision on decision-making on projects negatively affecting an SPA that in 1992 was replaced by Article 6 of the Habitats Directive, it is astonishing that it took until 2004 before the ECJ had to decide in a preliminary ruling on fundamental questions regarding the central provision of the Habitats Directive. There were earlier decisions in which Article 6 played a role, but in none of these the Court went into much detail. This, for instance, is the case in case C-57/89 Commission v Germany (Leybucht dykes) (ECR 1991 I-883) and case C-96/98 Commission v France (Poitevin marshes) (ECR 1999, I-1853) - both on Article 4(4) of the Wild Birds Directive, the predecessor of Article 6 of the Habitats Directive -, and in case C-117/00 Commission v Ireland (Owenduff-Nephin Beg Complex) (ECR 2002, I-5335) - on Article 6(2) -. Article 6(3) and 6(4) were mentioned in the Lappel Bank case, but this case was, like several others, mainly on the selection of sites as an SPA and on defining the boundaries of the SPA (case C-44/95 Regina v Secretary of State for the Environment ex parte Royal Society for the Protection of Birds, ECR 1996, I-3805). It is beyond any doubt that the current decision will be influential on much of the decision-making under the Wild Birds and Habitats Directives throughout the EU in the coming years.

The facts of the case are quite familiar to those involved in research in the Wadden Sea area. In the Netherlands, there is a fierce debate on the fishing for shellfish, especially mussels and cockles, in the Wadden Sea area. While the EVA II-research on the consequences of mechanical cockle fishing, financed by the Dutch government, was going on, environmental NGOs, fishermen and the competent authorities met in court regularly. Under Dutch law, each year, the fishermen have to obtain a licence stating the amount of shellfish they are allowed to catch in the current season. The amount granted depends on the amount of shellfish present; a certain percentage of the total amount is reserved for the birds. Each licence was challenged before the competent administrative court. From a legal point of view the main question in these court procedures was whether or not Article 6 should be applied in cases like these and, if so, how.

What is a 'project'?

The first issue that had to be resolved is whether or not fishing is a 'project' that is governed by procedure of Article 6(3). One could argue that fishing, like agriculture, is an ongoing, already existing activity from the past that is entirely different than a new project like the construction of building or a road. Many people, including the European Commission, always thought that the strict procedure of Article 6(3) did not apply to such activities. In its manual on Article 6, the European Commission explicitly states that Article 6(2) is 'applicable to the performance of activities which do not necessarily require prior authorisation, like agriculture or fishing.' (European Commission 2000a, p. 24). However, according to the Court, all interventions in the natural surroundings and landscape including those involving the extraction of mineral resources are subject to the procedure of Article 6(3). Doesn't this include practically any intervention, such as agriculture, recreation, fisheries, military activities, in other words: existing activities that were thought to not be regulated under Article 6(3)? The consequences of this decision cannot be thought of lightly. Any activity that is likely to have significant effects on the area is subject to Article 6(3)!

The precautionary principle

An appropriate assessment is necessary for projects that are likely to have a significant effect. The Court refers to the precautionary principle to explain the meaning of this provision. In case of doubt as to the absence of significant effects, an assessment must be carried out. The Court's intend is clear: it may not be easy to avoid making an assessment. The assessment has to show whether a project is damaging or not. Decision-making has to be based on facts, not on assumptions. In practice, under this condition, assessments will very often have to be carried out, since there usually is not that much knowledge on the (long term) effects of specific human activities on a specific habitat type or on a specific species. At the same time, we should acknowledge that uncertainties will always remain. Even the tremendous research effort that was delivered in the Netherlands to find out the consequences of shellfish fishing on the ecosystem of the Wadden Sea did not take away all uncertainties, and even came up with new ones. In my view, absolute certainty does not exist. At the end of the day, decision-makers have to assess the remaining uncertainties and potential consequences caused by these uncertainties. The European Commission also took this point of view (European Commission 2000b, sections 2 and 6.3.1).

What is 'significant'?

Unfortunately, the Court is very brief on the term 'significant'. The site's conservation objectives are decisive. Here, at first glance, the Court seems remarkably lenient: where a plan or project is likely to undermine the conservation objectives, the project must be considered to likely have a significant effect. Is this only the case when the site is totally lost for the habitat type or species for which is had been designated? Or when the quality of the habitat type deteriorates or the number of birds diminishes to such an extent that the area no longer qualifies as an SPA or SAC? These interpretations seem consistent with the word 'undermine'. Or is any damage to the conservation objectives 'significant'?

In national case law various approaches can be observed. In the Netherlands, courts sometimes argue that a negative effect is significant in case the area would no longer qualify as an SPA. In other decisions, courts consider any damage to the conservation objectives reason enough to have the competent authorities apply Article 6(3) (Verschuuren 2004b).

I support the latter view, as adequately put forward by the Advocate General in this case: If adverse effects resulting from projects were accepted on the grounds that they merely rendered the attainment of these objectives difficult but not impossible or unlikely, the species numbers and habitat areas would be eroded by them. It would not even be possible to foresee the extent of this erosion with any degree of accuracy because no appropriate assessment would be carried out. Indeed, long term viability of the area must be secured, so that must be the focus of any decision-making with regard to protected areas. It is remarkable to note that the Dutch and German versions of the judgement use the equivalent for the word 'endanger' rather than 'undermine', whereas the French version uses the equivalent of the word 'compromise' (compromettre).

Whatever the explanation of the word 'significant', the ECJ has placed so much emphasis on the precautionary principle, that it is clear that avoiding the duty to assess the consequences of a project will be very difficult, if not impossible. As already stated, there will almost always be uncertainty as to the potential consequences of a project, especially in a complex and dynamic ecosystem like the Wadden Sea, necessitating an assessment anyway. So in my view, the Court, by stressing the importance of the precautionary principle has rendered the discussion on the word 'significant' purely academic.

Appropriate assessment

The Court also clarifies the assessment itself. First of all, cumulative effects have to be taken into account. The project itself may not be harmful, but the project in conjunction with other projects may very well be harmful. Again, the Court does not fully clear up this point. Do only cumulative effects of future projects have to be taken into account, or the effects of existing projects as well (i.e., projects that were carried out in the past, such as an existing motorway)? And what about effects of autonomous developments, like the effects of climate change or invasive species? Both of these are effects play a big role in the Wadden Sea. In my view, such autonomous developments should be taken into consideration as well. The combined effects of fisheries and autonomous developments in the area might very well be much more harmful than the effects of fisheries alone. The problem here is that there is little that can be done to mitigate the effects of climate change. So it seems that the fishermen have to pay the bill!

Secondly, the assessment has to show that it is certain that the project will not adversely affect the integrity of the site. That is the case where no reasonable scientific doubt remains as to the absence of such effects. If doubt remains, the project cannot proceed unless Article 6(4) is applied. Again the precautionary principle plays a major role. It is applied in a very strict interpretation, much stricter than usual (Douma 2002 at 433). The strict interpretation is a consequence of the way Article 6(3) has been formulated. In this provision, the EC legislature opted for a strict implementation of the precautionary principle into a legal rule (Verschuuren 2003b). The Court rather tightly holds on to the literal text of Article 6(3).

Thirdly, it must be stressed that the effects on all conservation objectives must be assessed. For an area with such many conservation objectives, this is an enormous task. The Dutch part of the Wadden Sea has been designated for no less than 44 species of birds, five species of animals and nine habitat types. The potential effects of a project on all of these species and habitat types have to be assessed!

Discussion

Some critical remarks on this approach

The importance of this decision cannot be overestimated. As I already explained, it is a landmark decision that will be used by all courts throughout the EU in cases on areas protected under the Birds- and Habitats Directives. We already observed the impact in the Netherlands where courts strictly follow the words used by the European Court of Justice. The District Court of Amsterdam on 4 October 2004 annulled a licence for mechanical cockle fishing in the SPA Voordelta (part of the North Sea coastal zone), referring to the ECJ's judgement in case C-127/02. From a conservation point of view, the decision is hailed, especially by NGOs.

However, some critical remarks can be made as well. The cockle fisheries case itself shows the weaknesses of the directives. The conclusion of the EVA II-research project was that there are a number of factors that contribute to the decline of the number of shellfish-eating birds, some of which are beyond our control, such as climate change and -paradoxically- a successful European policy to decrease the level of eutrophication of surface waters, as well as the rapid proliferation of an invasive species (pacific oysters) (Ens et al. 2004). One of the factors is intensified fishing, which, by itself, accounts for a decline of around 15,000 oystercatchers. Mass mortalities of the common eider are probably due to over-fishing of intertidal mussel beds in the early 1990s, in combination with severe winter storms that delayed the recovery of the mussel beds. Other species, especially worm eating birds such as dunlins, have increased as a result of the disappearance of cockles and mussels. For policy makers, this leads to a tough situation. The SPA is not just designated for oystercatchers and eiders, but for a whole range of other species as well, including dunlins. Measures to restore the amount of food for shellfish-eating birds, will diminish the availability of food for worm eating birds and thus to a decline of these species. Also, one can rightfully ask whether taking the number of birds present in the year in which the area was designated as an SPA, is the right thing to do. As far as the western part of the Wadden Sea area is concerned, model calculations indicate the high level of eutrophication may have been the cause of an unnaturally high food supply in the past, and thus an unnatural high number of oystercatchers may have been present in the area (Ens et al. 2004). It is safe to assume that these numbers will never be achieved again, since nutrient loads are expected to decline further. In addition, the expected changes in climate might reduce the likelihood of large spatfalls of cockles and mussels, and the expected increase of the pacific oyster might go at the expense of other shellfish stocks (Ens et al. 2004). From a legal point of view this appears to be problematic. The dynamics of an ecosystem is not entirely consistent with the rather static conservation approach that the Wild Birds and Habitats Directives seem to take.

The future of shellfish fisheries in SPA Wadden Sea in the Netherlands

Meanwhile, the Dutch Parliament decided to ban mechanical cockle fishing from the Dutch Wadden Sea altogether, starting in 2005. This was not a direct consequence of the Court's judgement, but the outcome of a political debate on the future of the Wadden Sea area. The Minister decided to grant the fishermen one last licence for 2004. As usual, this licence was challenged by environmental NGOs. The European Court of Justice judgement came just a few days before the President of the Dutch Administrative Court had to render a decision in the (preliminary) suspension case on the 2004 licence (14 September 2004). He, obviously, decided that, given the judgement of the European Court, the licence had to be suspended awaiting formal sessions in court. A final decision in this case was taken in December 2004; as was expected, the Court annulled the permit (22 December 2004, Case Nos. 200000690/1-A and 200101670/1-A). On 9 February 2005, the 2002 permit was annulled as well, (Case No. 200305972/1). For the fishermen, the final decision was of no relevance, since the licence expired in January 2005 anyway.

In October 2004, the Dutch Minister of Agriculture, Nature, and Food Quality, published a new national policy for shellfish fisheries (Parliamentary Documents 2004). According to this policy document, mechanical cockle fisheries will be gradually abolished in other SPAs as well. The policy is aimed at a gradual transition to sustainable methods of shellfish fisheries (incl. mussels, oysters and other shellfish). Also, the policy document makes it clear that any fishing method that is likely to have a significant effect on a protected area will be subject to licensing under Article 6(3) of the Habitats Directive. In my view, it is correct not just to focus on mechanical cockle fisheries. Other methods can be harmful as well. Even handpicking of cockles, usually considered to be a sustainable fishing method, can have significant effects, for instance if a large number of people stroll through nesting areas of birds.

The future of the Wild Birds and Habitats Directives in the Wadden Sea area

Application of the provisions of the Wild Birds and Habitats Directives saw a slow start, all over Europe. In addition, especially as far as application of these Directives to the Wadden Sea is concerned, there has been an inconsistent start. Landmark decisions by the ECJ, such as the Wadden Sea shellfish case, usually have a big impact on legal practice in all EU Member States. Thus, this case may very well harmonize legal practice in the three Wadden Sea states, and in my view, is helpful in the efforts to integrate laws and policies with regard to the Wadden Sea, especially with regard to the application of Article 6.

In the Netherlands, the procedure of Article 6 of the Habitats Directive is used by interested stakeholders to look for possibilities to reconcile economic and conservation interests. Large, contested projects are negotiated by all parties involved, looking into nature protection issues for an entire region in an integrated fashion, and drawing up compensation plans to restore lost habitats. In my view, this development is based on the fact that courts in the last few years began to test projects against the provisions of the Habitats Directive. Because of the persistence of the European Commission, which continues to institute infringement procedures against EU Member States for failure to fulfil obligations under the Wild Birds and Habitats Directives, and because of the recent European Court decision in the cockle fisheries case, national authorities as well as national courts have come to realize the impact of these Directives.

NGOs have successfully seized the new opportunities offered by the European Directives to protest and combat the loss of biodiversity. The reason for the initial success of NGOs is simple: administrations were not accustomed to providing the amount of data, and legal arguments, that are now needed before a project that harms biodiversity can be approved. Courts tend to find administrative decisions inadequate, when the authorities are not able to present sufficient data. However, authorities, as well as developers now recognize that they need to develop their plans so as not to deteriorate protected areas or harm populations of endangered species. Their efforts must be applauded.

At the same time, the protests by these role players against the influence of the Habitats Directive on decision-making are becoming louder, not just in the Netherlands, but all over Europe. Until now, attempts to weaken the Habitats Directive have been averted. Instead, the European Commission has promised to evaluate the Wild Birds Directive and Habitats Directive in 2007. This evaluation has to show whether amendments are in order.

In my view the critique is not justified. Indeed, many decisions have been annulled by courts, especially in the Netherlands, but mainly because the competent authorities did not carry out an assessment at all, or did not follow the correct procedure. In the end, most projects were allowed, after the correct procedure was followed. Often, the assessment under Article 6 of the Habitats Directive shows that it possible to go ahead with a project, usually in a more or less adapted form, for instance, on a smaller, less harmful, scale, or with additional measures to mitigate the effects.

In my view, there will be two challenges for the near future. The first challenge is to adapt the rather static conservation approach that the legal system now takes to the dynamics of ecosystems. Joint research by lawyers and biologists has to show how this must be done without weakening the legal protection of protected areas. The second challenge is to reconcile habitat protection and economic activities. The Wild Birds Directive and Habitats Directive offer enough possibilities for the parties involved to negotiate such reconciliation. All parties involved in the Wadden Sea area (local residents, environmental NGOs, business corporations, public authorities), together will and can find ways to achieve the targets set by the Wild Birds Directive and Habitats Directive without disregarding all economic or social interests. To accomplish this, a strong Habitats Directive is necessary, a tiger that still has all its teeth!

References

Backes, Ch.W., Freriks, A.A., Nijmeijer, A.G.A. forthcoming: Rechtsvergelijkend onderzoek implementatie artikel 6 Habitatrichtlijn. Centrum voor Omgevingsrecht/NILOS, Utrecht (forthcoming March 2006).

Bastmeijer, C.J., Goedhart, A.F.F., Hoitink, J.E., Knot, H.J.P., Osieck, E.R., Verschuuren, J.M., Van der Zwiep, K. 2001: Europees en internationaal natuurbeschermingsrecht in Nederland, Een nadere bestudering van de gevolgen van de Vogel- en Habitatrichtlijn en het Verdrag van Bern in Nederland. Vereniging voor Milieurecht 2001-1, Boom Juridische uitgevers, Den Haag.

De Sadeleer, N., Roller, G., Dross, M. 2005: Access to Justice in Environmental Matters and the Role of NGOs. Empirical Findings and Legal Appraisal. Europa Law Publishing, Groningen.

Douma, W. Th. 2002: The Precautionary Principle. Its Application in International, European and Dutch Law. Dissertation. Groningen.

Ens, B.J., Smaal, A.C., De Vlas, J. 2004: The effects of shellfish fishery on the ecosystems of the Dutch Wadden Sea and Oosterschelde. Alterra, Wageningen.

European Commission 2000a: Managing Natura 2000 Sites. The Provisions of Article 6 of the 'Habitats' Directive 92/43/EEC. Luxembourg.

European Commission 2000b: Communication from the Commission on the Precautionary Principle. COM(2000)1.

Gellermann, M. 2004: Herzmuschelfischerei im Lichte des Art. 6 FFH-Richtlinie. -Natur und Recht 12: 769-773.

Oxford Brookes University 2003: Review of International Legal Instruments, Policies and Management in respect of the Wadden Sea Region. Impact Assessment Unit, Oxford.

Parliamentary Documents 2004: Room for a salty harvest. Towards a transition in Dutch shellfish fisheries (2005-2020). Parliamentary Documents II 29 673, No. 3. The Hague.

Verschuuren, J. 2002: Implementation of the Convention on Biodiversity in Europe: 10 years of Experience with the Habitats Directive. - Journal of International Wildlife Law and Policy 3: 21-267.

Verschuuren, J. 2003a: Effectiveness of Nature Protection Legislation in the EU and the US: The Birds and Habitats Directives and the Endangered Species Act. - In: Somsen, H., T.F.M. Etty, J. Scott, L. Krämer (eds.); Yearbook of European Environmental Law, Vol. 3. Oxford University Press, Oxford, pp. 305-328.

Verschuuren, J. 2003 (b): Principles of Environmental Law. The Ideal of Sustainable Development and the Role of Principles of International, European, and National Environmental Law. Nomos Verlag, Baden-Baden.

Verschuuren, J. 2004a: Effectiveness of nature protection legislation in the European Union and the United States: The Habitats Directive and the Endangered Species Act. - In: Dieterich, M., J. van der Straaten (ed.); Cultural Landscapes and Land Use: The Nature Conservation-Society Interfac. Kluwer Academic Publishers, Dordrecht, Boston, London, pp. 39-67.

Verschuuren, J. 2004b: Case law analysis with District Court Leeuwarden 31 December 2003 and Administrative Law Division of the Council of State 17 December 2003. Milieu en Recht 3: 203-212.

Verschuuren, J. 2005: Shellfish for Fishermen or for Birds? Article 6 Habitats Directive and the Precautionary Principle. - Journal of Environmental Law 2: 265-283.

EU Directives and their effects on the ecosystem of the Wadden Sea

Francisciscus Colijn & Stefan Garthe

Colijn, F. & Garthe, S. 2006: EU Directives and their effects on the ecosystem of the Wadden Sea. In: Monitoring and Assessment in the Wadden Sea. Proceedings from the 11. Scientific Wadden Sea Symposium, Esbjerg, Denmark, 4.-8. April 2005 (Laursen K. Ed.). NERI Technical Report No. 573, pp. 13-20.

Three EU Directives, the Bird Directive, the Habitat Directive and the Water Framework Directive, aim to protect the environmental quality or even specific groups of organisms, or habitats with their associated flora and fauna, in the European member states.

The realisation and control of these directives is not an easy task and therefore it seems relevant to assess to which extent these directives are helpful in reaching the goals of preservation, restoration or improvement of the ecosystem of the Wadden Sea.

It should be realized that systems such as the Wadden Sea are open in a sense that many of the species under these directives can freely migrate in and out of the Wadden Sea, or that habitats are exposed to large natural variability in abiotic environmental conditions. This paper evaluates two aspects: are these directives helpful in preserving the status of the Wadden Sea, and secondly can we assess this status in view of the directives. We used examples from different groups of organisms to answer these questions.

A conclusion of this paper is that at present the long-term effects of these directives cannot be evaluated because of the complexity of the system and the inability to discriminate between measures from the directives and other ongoing environmental improvements such as reduction of eutrophication and of the inputs of contaminants.

Keywords: Wadden Sea, ecosystem, conservation, EU directives, OSPAR, eutrophication

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Introduction

Since the late seventies the EU has started to formulate Directives. One of the first released was the so-called Wild Birds Directive (Anonymous 1979). The intention of this directive is that member States shall take measures to preserve, maintain or re-establish a sufficient diversity and area of habitats for all the species of birds referred to in Article 1 (Wild Birds Directive: Anonymous 1979). The objective of the special measures is to conserve their habitat in order to ensure their survival and reproduction in their area of distribution. Therefore the Member States are urged to classify in particular the most suitable territories in number and size as special protection areas, taking into account their requirements in the geographical sea and land area where this Directive applies.

In 1992, the EU presented another Directive which is known as the Habitat Directive (Anonymous 1992). This directive on the conservation of natural habitats and of wild fauna and flora asks the Member States to create a coherent network of protected areas. The purpose of this network is to preserve terrestrial, freshwater and marine biological diversity. A special part of this directive is devoted to the protection of a number of marine mammals such as the harbour porpoise, the common seal and the grey seal. Other elements under the Habitat Directive are salt marshes and sea-grasses as traditional elements of the flora of the Wadden Sea.

In 2000 the EU promoted an important directive which is known as the European Water Framework Directive (WFD) (WFD 2000). This directive is meant to protect the aquatic systems, freshwater, as well as estuarine and coastal waters. Objectives are the maintenance of a good ecological status, control of environmental damage at the source, and use of the precautionary principle, to enable an economic and social development of the EC countries, but with a regional differentiation. It urges for international co-operation and methodology development. For this purpose the WFD has compiled biological and physico-chemical quality elements (e.g. WFD 2000, Annex V), such as phytoplankton, macroalgae, angiosperms, benthic invertebrates and fish. Sensitivity, abundance and diversity within these groups are the key elements for the determination of the ecological status.

A rather specific case similar to the WFD is the OSPAR Directive (OSPAR 1997). The OSPAR Commission has adopted a so-called common procedure for the assessment of the eutrophication status of the maritime area of the OSPAR Convention area. This common procedure distinguishes three types of areas. Problem areas with evidence for an undesirable disturbance due to anthropogenic enrichment by nutrients, potential problem areas which have reasonable grounds for concern that disturbance may occur and non-problem areas for which concerns do not exist. For the Wadden Sea region specific criteria have been developed by van Beusekom et al. (2001).

In this paper we will evaluate to which extent these directives have been helpful to reach the goals of preservation and protection. For the WFD this is not yet possible, because the execution of the directive is not yet achieved. Because of the long-term effects of such directives a clear proof of their effectiveness will currently be impossible.

Material and methods

Published as well as unpublished material and information from different sources have been used for this paper. Information on birds has been taken from monitoring studies in the Wadden Sea such as data on Brent and Barnacle goose as well as several waders which were derived from studies published by the National Park Administration of Schleswig-Holstein (e.g. NPA 2000); data on gulls were made available from our own FTZ database; the data on the population size of common seals in the Wadden Sea are taken from the recent Reijnders et al. (2005) publication. Data on the distribution of marine mammals were taken from several sources such as Haelters et al. (2002), Camphuysen (2004) and unpublished data from running projects at the FTZ. Information about salt marshes and sea-grasses were taken from the Bakker et al. (2005) and Reise et al. (2005) papers. Data on eutrophication in the Wadden Sea are from van Beusekom et al. (2001), OSPAR (2003), van Beusekom et al. (2005) and van Beusekom (2005; unpubl.).

Results and Discussion

Wild Birds Directive

Nine examples of bird species which fall under the Wild Birds Directive are presented. The best documented long-term series on numbers of breeding pairs are available for the Sandwich Tern *(Sterna sandvicencis).* In Fig. 1 the development of breeding pairs is shown for different regions of the Wadden Sea, in Denmark, Schleswig-Holstein, Lower Saxony and the Netherlands.

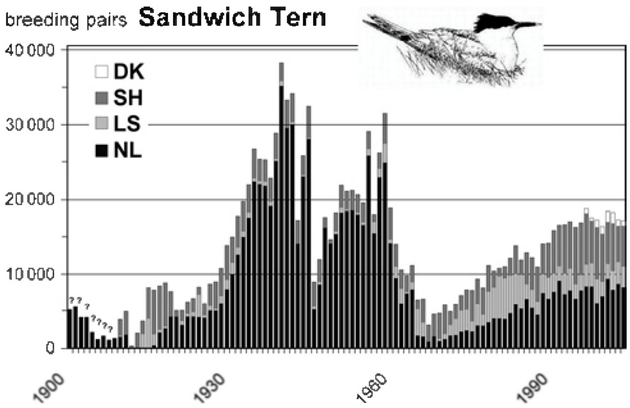

Figure 1. Breeding pairs of the Sandwich Tern in different parts of the Wadden Sea. DK: Denmark; SH: Schleswig-Holstein; LS: Lower Saxony; NL: the Netherlands; Source: Nationalparkamt, Tönning.

Although numbers for the early part of the 20th century are not completely reliable, the long-term development shows a few characteristics, such as a strong increase from the nineteen thirties onwards, and a strong decrease almost to extinction in the mid sixties. Afterwards a slow but steady increase has occurred with a stabilisation of the numbers at about half the maximal numbers of the nineteen forties. The decrease in the sixties was due to water pollution from the Rotterdam area by polychlorinated compounds which accumulated in the birds through the food-web (Koeman 1971). After reducing the discharges a slow but steady recovery took place. However the graph shows a substantial shift of the breeding colonies to the north (Rasmussen et al. 2000). The reason for this is unknown.

Two goose species in the Schleswig-Holstein part of the Wadden Sea show opposite directions of population developments (Fig. 2). Whereas the Barnacle Goose *(Branta leucopsis)* is steady increasing over the last two decades, the Brent Goose *(Branta bernicla)* shows a steady decline. For both species the overall changes in numbers, distribution and habitat utilization in the Wadden Sea seem to be mainly related to changes at the population level (Blew et al. 2005). No evidence has been found that changes in the decline or increase in either species, although feeding opportunities did change during the past

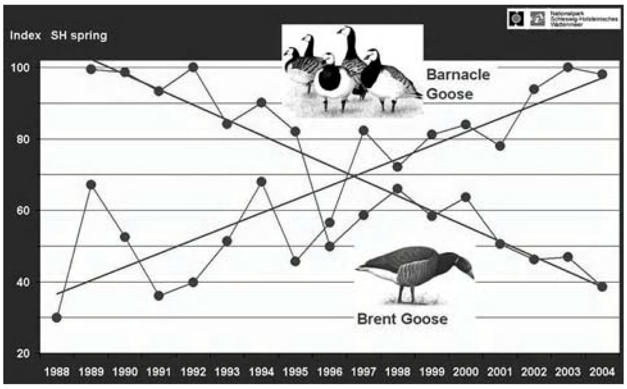

Figure 2. Development of numbers of two goose species: Barnacle and Brent Goose in Schleswig-Holstein (German Wadden Sea) Source: Nationalparkamt, Tönning.

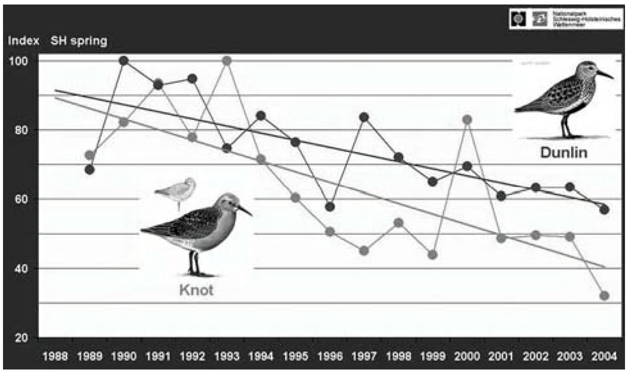

Figure 3. Development of numbers of Knot and Dunlin in Schleswig-Holstein; Source: Nationalparkamt, Tönning.

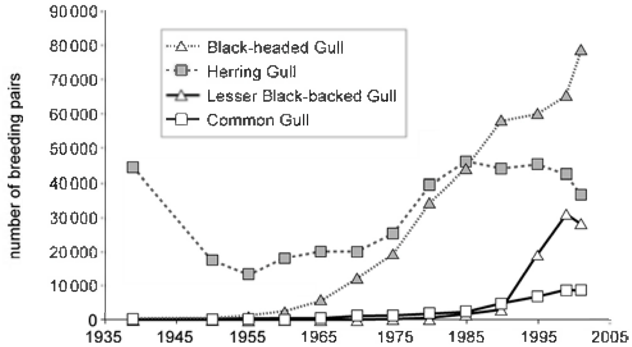

Figure 4. Development of numbers of four gull species along the German North Sea coast. Source: Garthe et al. (2000, unpubl.).

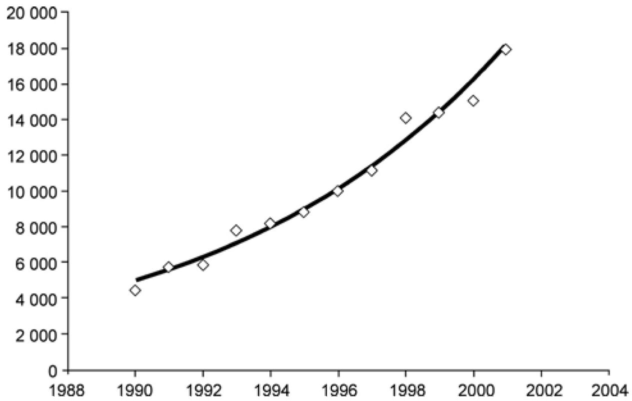

Figure 5. Growth rates of seals in the Wadden Sea on the basis of annual aerial counts (Source: Reijnders et al. 2005).

decades with the abandoning of livestock grazing in large parts of the salt marshes (Blew et al. 2005). Two other factors might have influenced the population size and distribution: a change in timing of migration, and the management of grasslands in the eastern part of the Wadden Sea (Blew et al. 2005).

In Fig. 3 two examples of the decline of typical Wadden Sea waders, are shown. Dunlin *(Calidris alpina)* and Knot *(Calidris canutus)* both show a steady decline over the last two decades. Although no final analysis exists, the supposition is that through a complex of factors the availability of food for these bird species has been reduced.

A final example shows the population size development of four different gull species with different food preferences and foraging strategies: the Black-headed *(Larus ridibundus)*, the *Herring (Larus argentatus)*, the Lesser Black-backed *(Larus fuscus)* and the Common Gull *(Larus canus)* (Fig. 4). All of them show a steady increase in numbers along the German North Sea coast since the mid-1950s. The last three species seem to stabilize in population size in the nineties whereas the numbers of the black-headed gull still increase. Part of the changes in these population sizes can be explained by food availability, especially for those species which have the ability to exploit both natural and anthropogenic food sources like discards and offal.

According to the Blew et al. (2005) review of overall trends in water birds utilizing the Wadden Sea, 22 out of 34 species considered experienced declines in the 1992-2000 period, of which 15 are statistically significant. This looks like an alarming development since the 1999 QSR. Moreover, similar declines have not been observed elsewhere, suggesting that the causes for these declines may be related to the Wadden Sea area (Blew et al. 2005). These declines prevent us from demonstrating an overall positive effect of the Birds Directive. However, a conclusion on the effectiveness of the Birds Directive cannot easily be drawn as the conditions might have been worse without such a protective status.

Habitat directive

Apart from special protection status for a selected group of marine mammals like harbour porpoise, common and grey seals, another element of the Habitat Directive (Anonymous 1992) is the creation of a coherent network of protected areas. For this purpose the whole Wadden Sea and larger parts of the coastal seas as well as the German Exclusive Economic Zone (EEZ) of the North and Baltic seas have been declared as protected areas or are candidates for such.

HARBOUR PORPOISE
Phocoena phocoena

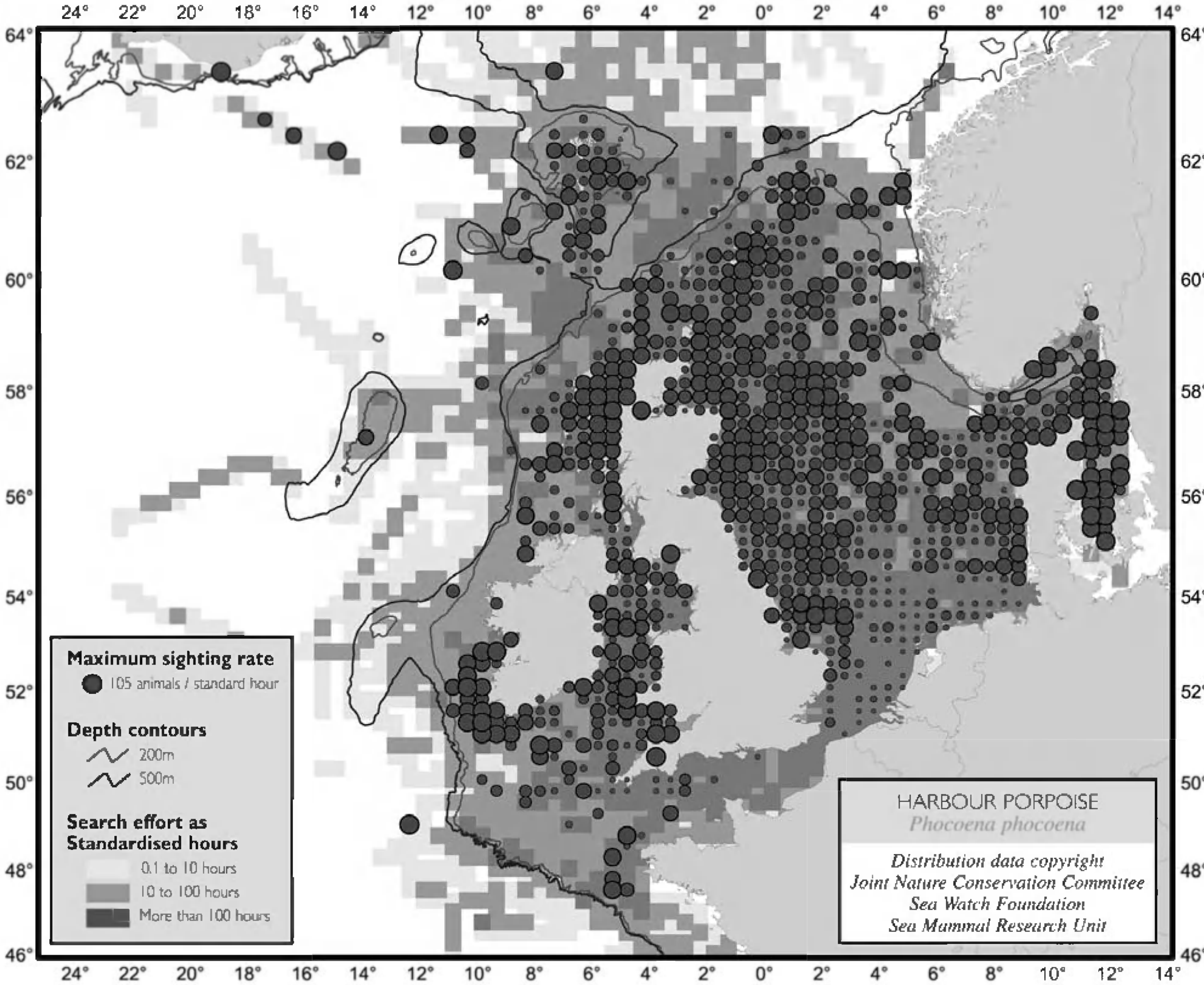

Figure 6. Counts of harbour porpoises in the North Sea and around the British Isles (Source: Reid et al. 2003).

Although seals were affected twice by Phocine Distemper virus epidemics during the last two decades which both about halved the population of the common or harbour seals (*Phoca vitulina*; Härkönen et al. 2006), the population still seems to be able to recuperate extremely fast based on the annual growth rates of the population (Fig. 5). Thus the population recovered within about 7 years to the pre-epidemic levels after the first devastating epidemic in 1988. A similar expectation exists for the present situation after another epidemic in 2002. This means that living conditions for seals inside the Wadden Sea and the adjacent coastal North Sea must be sufficiently good regarding food availability and resting places. Whereas indications for contaminant burdens are only partly available these do not seem to strongly affect the growth rate of the population, although the level of contamination is still beyond natural levels. On the basis of studies in the Netherlands after the first virus outbreak de Swart et al. (1996) concluded that contamination deteriorates the immune system that acts as a defense mechanism against virus attacks.

Harbour porpoises *(Phocoena phocoena)* are categorized according to the Habitat Directive as vulnerable. Our information on the numbers and distribution of these animals is much more scattered and less reliable than on harbour seals e.g., due to the way these animals live. Several sources however strongly suggest that the numbers of these animals increase (Haelters et al. 2002, Camphuysen 2004). A clear seasonal pattern was observed along the Dutch coast (Camphuysen 2004). Fig. 6 shows a compilation of observations in the North Sea as well as the waters surrounding the British Isles. Currently, many efforts are made to improve these population estimates based on flight and ships (Scheidat et al. 2004).

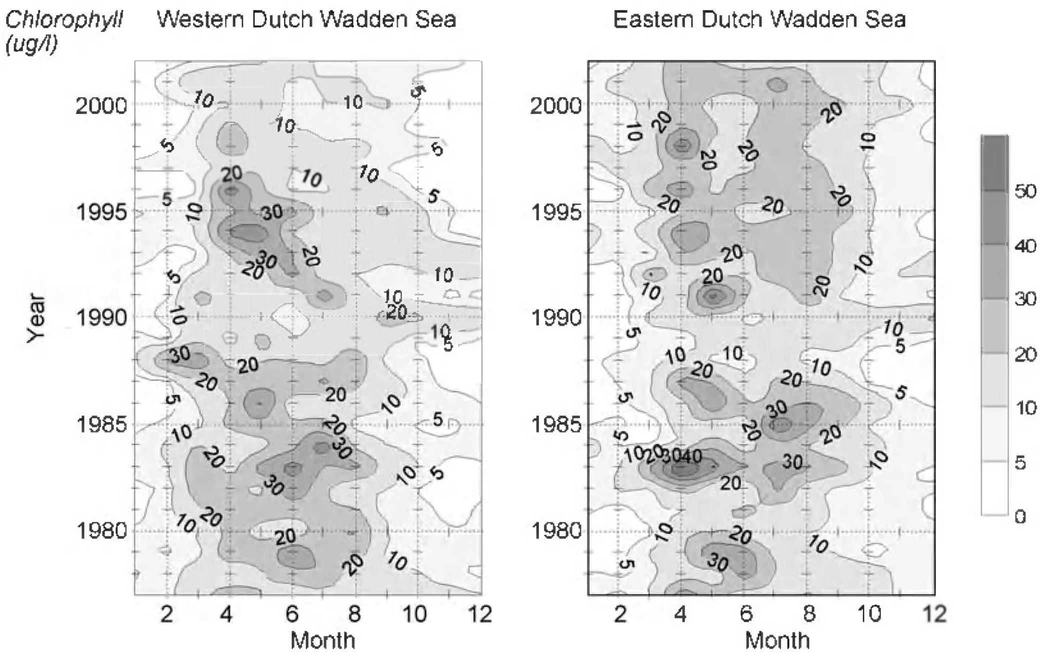

Figure 7. Specific Total Phosphate (TP) and Total Nitrogen (TN) loads in the Rhine, Maas, Scheldt (open symbols) and the Elbe-Weser (closed symbols); Source: van Beusekom et al. (2005).

Offshore from the Island of Sylt a protection area for harbour porpoises has been established, based on the relatively high density of animals, the all year occurrence and the presence of calves. More extended protective areas within the German EEZ have been proposed.

Other habitats which have obtained protective status are salt marshes and sea-grasses. Since 1994 a regular monitoring based on aerial surveys occurs. The data suggest a steady recovery in the North Frisian Wadden Sea (cf. Bakker et al. 2005, Reise et al. 2005). Because of the high long-term variability (e.g. 1991) it is difficult to find a clear cause for the ongoing increase. Reduction of eutrophication causing less epiphytes or an improved underwater light climate could be one of the possibilities.

Salt marshes have attracted much attention since they were under anthropogenic pressure through e.g. grazing by cattle and sheep. There is a continued discussion on the targets set such as 'natural salt marshes' which depicts a controversy between high diversity versus natural development. Over the last decades a clear decrease of the mainland salt marsh areas with intensive grazing can be observed in Schleswig-Holstein (Bakker et al. 2005). In conclusion, it seems that the Habitat Directive at least helps to consolidate the present situation showing no further declines in these specific habitats.

The European Water Framework Directive

Principles and objectives of the WFD are the protection and maintenance of the aquatic environment with a good ecological status, and a control of environmental damage at the source. At the same time an economic and social development of the EC, with a regional differentiation should be possible. International cooperation and the joint development of methodologies are emphasized for the WFD. Because the WFD is still in the phase of defining the biological and physico-chemical quality elements, and in a discussion on the criteria to be used for setting quality objectives, no conclusions regarding the original question can be drawn, but implementation of the WFD will put strong emphasis on improvements of the environmental and ecological quality of estuarine and coastal waters.

OSPAR Directives on Eutrophication

Very similar to the WFD is the development within the Oslo and Paris Convention (OSPAR) of directives for eutrophication. After a long international debate (de Jong 2006) the nations have adopted a so-called common procedure for the identification of the eutrophication status of the Maritime Area of the OSPAR Convention (OSPAR 1997). In this common procedure three types of areas are distinguished on the basis of a set of criteria: problem areas, potential problem areas and non-problem areas. Because eutrophication has regional characteristics, special region specific criteria were developed for the Wadden Sea (van Beusekom et al. 2001). These region specific criteria have been categorized into three groups: causative factors (cat. I), supporting factors (cat. II) and direct effects (cat. III).

A large amount of information is available on the eutrophication status of the Wadden Sea. As shown in Table I the Wadden Sea is assessed as problem area according to the assessment criteria by all three Wadden Sea countries. As an example of the causa-

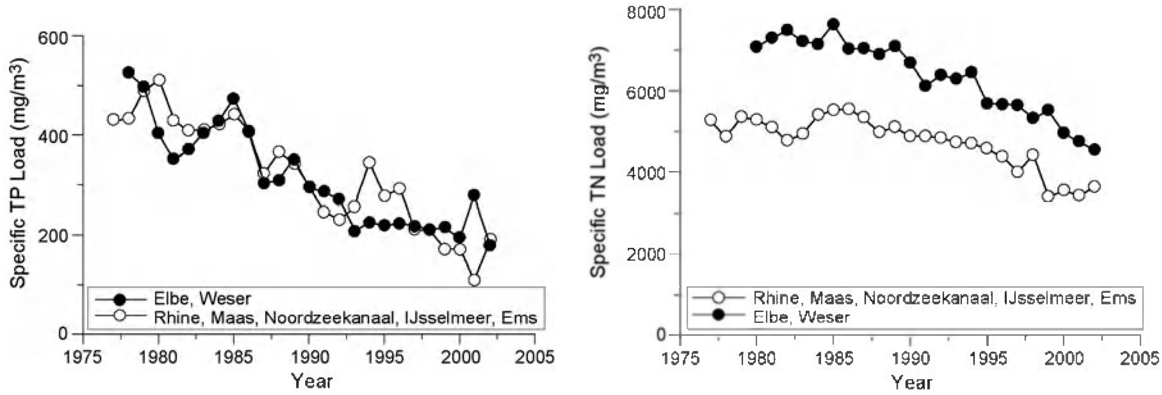

Figure 8. Long-term chlorophyll-a concentration in the Dutch western and eastern Wadden Sea.(Source: van Beusekom et al. 2005).

Table 1. Summary of the Wadden Sea Eutrophication Assessment by OSPAR (OSPAR 2003). All three Wadden Sea countries assessed the Wadden Sea as a problem area. + = increased trends, elevated levels, shifts or changes, - = no increased trends, no elevated levels, no shifts or changes, ? = not enough data to perform an assessment, NT = not taken into account, Empty cells = parameters not used.

	Netherlands	Germany	Denmark
Cat I: River. Input (50% above background)	+	+	+
Winter Concentrations*	+	+	+
N/P ratios	+	+	+
Cat II: Chlorophyll (Max. >22-24 µg/l)	+	+	+
Phytoplankton Indicator Species	+	+	-
Macrophytes	+	+	+
Cat III: Oxygen Problems	+	?	-
Changes/Kills of Macrobenthos	NT	?	-
Changes in organic matter	+	?	
Cat IV: Algal toxins	+	+	+

* Wadden Sea (>6-7 µM N), Estuaries (>18-30 µM N)

tive factors nutrient loads to the Wadden Sea have been used. Fig. 7 shows the specific total phosphate (TP) and total nitrogen (TN) loads from 1975 till 2002. The trends in these data are clear: TP has been reduced to one third of the 1975 values whereas the TN loads have been reduced by ca. 40%. Although the catchments show quantitative differences, the trend-like decrease is similar in both the Rhine and Elbe catchments.

Although the decreases in loads have been large and highly significant, it is much more difficult to observe consequences of these reductions for the direct effects such as phytoplankton biomass measured as chlorophyll-a. Fig. 8 shows the seasonal and decadal variability of chlorophyll-a for both the Western and Eastern Dutch Wadden Sea: at least a reduction in the intensity of the main blooms can be observed despite the high variability between years. A comparable decrease cannot be observed for the Sylt-Rømø Bight in the northern German Wadden Sea and for the island of Norderney in the Lower Saxonian part of the Wadden Sea (cf. van Beusekom et al. 2005).

In conclusion: some clear changes in nutrient loads have been detected whereas it seems to be more difficult to detect trends in the parameters linked to direct effects such as chlorophyll-a concentrations.

A question which has remained unsolved until today is whether the changed N/P ratio due to the enhanced reduction of phosphate as opposed to nitrogen compounds could have detrimental effects by causing an increased occurrence of toxic algae. Although many toxic algal blooms have been observed along the European coasts over the last decade it is difficult to show that there is a causal link to the state of eutrophication (ICES 2003).

In conclusion, the decrease in riverine nutrient loads is starting to affect the eutrophication status of the Wadden Sea. Evaluation of chlorophyll and nutrient data from the Wadden Sea indicate that in some parts of the Wadden Sea the amount of organic matter turnover is decreasing. Also the summer chlorophyll concentration is decreasing in response to the decreasing riverine nutrient loads (van Beusekom et al. 2005). Long-term primary production data in the Western Dutch Wadden Sea decrease gradually since maximum values were reached during the 1990s (Cadee & Hegeman 2002).

Another eutrophication related change recorded in the Wadden Sea was the increase of green macroalgae from the late 1970's to a peak in 1990-1993. Now first signs of improvement are becoming visible. Regular observations in the northern Wadden Sea indicate that that the area covered with green macroalgae is gradually decreasing. In 2004 it reached for the first time the marginal occurrences prior to the 1980's (van Beusekom et al. 2005).

General conclusions

The level of protection of plants and animals, as well as of habitats has strongly improved over the last three decades. Plant and animal life shows large regional, temporal and spatial variability. Therefore conclusions on increase or decrease of selected animals and plant species are seldom related to simple cause and effect relationships. Multi-factorial causes are much more common in nature and hinder simple explanations. Therefore it is impossible to confirm either in a positive or negative sense that EU directives have had a direct impact on the ecosystem of the Wadden Sea or coastal shelf sea. This is different for the impact of the OSPAR eutrophication common procedure and its reduction measures taken after political action.

Long-term observations of selected animal and plant species are needed for scientific analyses of observed changes. Supporting experimental work will be needed to establish causal explanations. The establishment of LTER (Long Term Ecological Research) areas would be a good mechanism to improve our understanding of long-term changes in the marine environment.

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References

Anonymous, 1979. Wild Birds Directive, EU Commission, 79/409/EEC.

Anonymous, 1992. Habitat Directive of the European commission, 92/43/EEC.

Bakker, J.P., J. Bunje, K. Dijkema, J. Frikke, N. Hecker, B. Kers, P. Körber, J. Kohlus & M. Stock 2005. Salt marshes. In: Essink, K., C. Dettmann, H. Farke, K. Laursen, G. Lüerßen, H. Marencic & W. Wiersinga (eds.): Wadden Sea Quality Status Report 2004. Wadden Sea Ecosystem 19: 163-179.

Blew, J., K. Eskildsen, K. Günther, K. Koffijberg, K. Laursen, P. Potel, H.-U. Rösner, M. van Roomen & P. Südbeck 2005. Migratory birds. In: Essink, K., C. Dettmann, H. Farke, K. Laursen, G. Lüerßen, H. Marencic & W. Wiersinga (eds.): Wadden Sea Quality Status Report 2004. Wadden Sea Ecosystem 19: 287-304.

Cadee, G.C., & J. Hegeman, 2002. Phytoplankton in the Marsdiep at the end of the 20th century; 30 years monitoring biomass, primary production, and Phaeocystis blooms. Journal of Sea Research 48: 97-110

Camphuysen, C.J., 2004. The return of the harbour porpoise (Phocoena phocoena) in Dutch coastal waters. Lutra 47: 113-122.

de Jong, F., 2006. Marine eutrophication in perspective on the relevance of ecology for environmental policy. PhD Thesis University of Groningen. Springer, Heidelberg.

De Swart, R.L., Ross, P.S., Vos, J.G., and. Osterhaus, A.D.M.E. (1996). Impaired immunity in harbour seals (Phoca vitulina) exposed to bioaccumulated environmental contaminants: review of a long-term feeding study. Environmental Health Perspectives 104 Suppl. 4, 823-828.

Garthe, S., B.-O. Flore, B. Hälterlein, O. Hüppop, U. Kubetzki & P. Südbeck 2000. Die Brutbestandsentwicklung der Möwen (Laridae) an der deutschen Nordseeküste in der zweiten Hälfte des 20. Jahrhunderts. Vogelwelt 121: 1-13.

Haelters, J., T. Jauniaux & J. Van Gompel 2002. Increased numbers of harbour porpoise strandings in Belgium between 1990 and 2001. Poster 16th Annual Meeting European Cetacean Society, Liege, 7-11 April 2002.

Härkönen, T., R. Dietz, P. Reijnders, J. Teilmann, P. Thompson, K. Harding, A. Hall, S. Brasseur, U. Siebert, S.J. Goodman, P.D. Jepson & T.D. Rasmussen, 2006. Review of seal epizootics in Europe, 2006. Journal of Diseases of Aquatic Organism 68: 115-130.

ICES, 2003. Environmental Status of the European Seas. International Council for the Exploration of the Sea, Copenhagen.

Koeman, J.H. 1971. Het voorkomen en de toxicologische betekenis van enkele chloorkool-water-

stoffen aan de Nederlandse kust in de periode van 1965 tot 1970. PhD Thesis, Landbouwhogeschool Wageningen, the Netherlands, 139 pp.
OSPAR, 1997. OSPAR Agreement 1997-17: The common procedure for the identification of the eutrophication status of the OSPAR Maritime Area. OSPAR Commission, London.
OSPAR, 2003. OSPAR integrated report on the Eutrophication Status of the OSPAR Maritime Area based upon the first application of the Comprehensive Procedure. OSPAR Commission, London.
Rasmussen, L.M., D.M. Fleet, B. Hälterlein, B.J. Koks, P. Potel & P. Südbeck, 2000. Breeding birds in the Wadden Sea in 1996 – Results of a total survey in 1996 and of numbers of colony breeding species between 1991 and 1996. Wadden Sea Ecosystem 10: 1-122.
Reid, J.B., P.G.H. Evans & S. Northridge, 2003. Atlas of the cetacean distribution in north-west European waters. Joint Nature Conservation Committee, Peterborough, 76 pp.
Reijnders, P.J.H., K.F. Abt, S.M.J.M. Brasseur, C.J. Camphuysen, B. Reineking, M. Scheidat, U. Siebert, M. Stede, J. Tougaard & S. Tougaard 2005. Marine mammals. In: Essink, K., C. Dettmann, H. Farke, K. Laursen, G. Lüerßen, H. Marencic & W. Wiersinga (eds.): Wadden Sea Quality Status Report 2004. Wadden Sea Ecosystem 19: 305-318.
Reise, K., Z. Jager, D. de Jong, M. van Katwijk & A. Schanz 2005. Sea grass. In: Essink, K., C. Dettmann, H. Farke, K. Laursen, G. Lüerßen, H. Marencic & W. Wiersinga (eds.): Wadden Sea Quality Status Report 2004. Wadden Sea Ecosystem 19: 201-207.
Scheidat, M., Kock, K.-H., Siebert, U. 2004. Summer distribution of harbour porpoise (Phocoena phocoena) in the German North and Baltic Sea. Journal of Cetacean Research and Management 6: 251-257.
van Beusekom, J., P. Bot, J. Göbel, M. Hanslik, H.-J. Lenhart, J. Pätsch, L. Peperzak, T. Petenati & K. Reise 2005. Eutrophication. In: Essink, K., C. Dettmann, H. Farke, K. Laursen, G. Lüerßen, H. Marencic & W. Wiersinga (eds.): Wadden Sea Quality Status Report 2004. Wadden Sea Ecosystem 19: 141-154.
van Beusekom, J.E.E., H. Fock, F. De Jong, S. Diel-Christiansen & B. Christiansen, 2001. Wadden Sea specific eutrophication criteria. Wadden Sea Ecosystem 14: 1-116.
van Beusekom, J.J.E., 2005. A historic perspective on Wadden Sea eutrophication. Helgoländer Marine Research 59: 45-54.
NPA (Landesamt für den Nationalpark Schleswig-Holsteinisches Wattenmeer) (ed.), 2000. Wattenmeermonitoring 1998. Schriftenreihe des Nationalparks Schleswig-Holsteinisches Wattenmeer, Tönning.
WFD, 2000. European Water Framework Directive.2000/60/EC.

Monitoring demands for administration and managers

Anton Beck

Beck, Anton 2006: Monitoring demands for administration and managers. In: Monitoring and Assessment in the Wadden Sea. Proceedings from the 11. Scientific Wadden Sea Symposium, Esbjerg, Denmark, 4.-8. April, 2005 (Laursen, K. Ed.). NERI Technical Report No. 573, pp. 21-25.

As responsible for the implementation of EU nature directives, a.o. Birds and Habitats Directive and the Wadden Sea Cooperation I want to focus on "Monitoring Demands for Administration and Managers". The presentation will be divided into the following five sections:

- Wadden Sea monitoring and management history
- Wadden Sea monitoring and management challenges
- EU monitoring and management challenges
- Danish Experience
- Conclusion

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Wadden Sea monitoring and management history

More than twenty years ago, in 1982, the three Wadden Sea countries recognized their responsibilities for the conservation of the Wadden Sea ecosystem. This was made clear in the Joint Declaration, which created the basis for the Trilateral Wadden Sea Cooperation. This also marked the beginning of considerations of joint monitoring of the environment of the Wadden Sea. The principles and the general outline of a trilateral joint monitoring programme, including the associated data management, were adopted ten years later, in 1993, by the Senior Officials of the Wadden Sea Cooperation.

A few years later, in 1995, the DEMOWAD project was initiated. This project developed a set of monitoring guidelines and a prototype of data management, streamlined for Wadden Sea monitoring and assessment. Already in 1997, at the Stade Governmental Conference, the results of the DEMOWAD project led to the ministerial agreement to implement a Trilateral Monitoring and Assessment Programme (TMAP), which consisted of the Common Package of 28 parameter groups and the associated data management.

Until now, three Wadden Sea Quality Status Reports have been issued on this basis. The reports present comprehensive data collected from the years investigated, and form the basis for the present work. And what is more: the reports have provided important input to the political decisions on the further management of the Wadden Sea that have been made at the Governmental Conferences.

I fully share the view of Karel Essink (2006) in underlining the importance of the QSR as a tool for transforming monitoring results into the political decision-making and management, and would like to point at the importance of this bridge between data collection and the political/administrative decisions.

In the recent Governmental Conference at Esbjerg in 2001, the ministers agreed to have the TMAP Common Package, including the data handling system, implemented by the end of 2002, and to have it evaluated by 2004. Further, the ministers underlined the need to further optimize the TMAP for future requirements, in particular with regard to the EU Habitats Directive and the EU Water Framework Directive, and, to this end, to:

1) make use of data from existing monitoring programmes, and to evaluate possibilities of including them into TMAP without additional costs, and
2) prepare proposals for the further development of TMAP by the 2005 Governmental Conference.

Wadden Sea monitoring and management challenges

The evaluation of the data handling system, made by The Orbis Institute, was presented in 2004 and revealed also the future challenges for the Wadden Sea monitoring and assessment.

From a Danish point of view, the evaluation also marked a milestone for more general considerations regarding Wadden Sea monitoring. Especially in the context of the newly established, general Danish Environment and Nature Monitoring and Assessment Programme, NOVANA, this entered into force the 1st of January 2004, as well as in the context of EU monitoring, assessment and reporting obligations within the Habitats Directive, the Birds Directive and the Water Framework Directive. However, it is of course important to consider these developments in the context of limited resources.

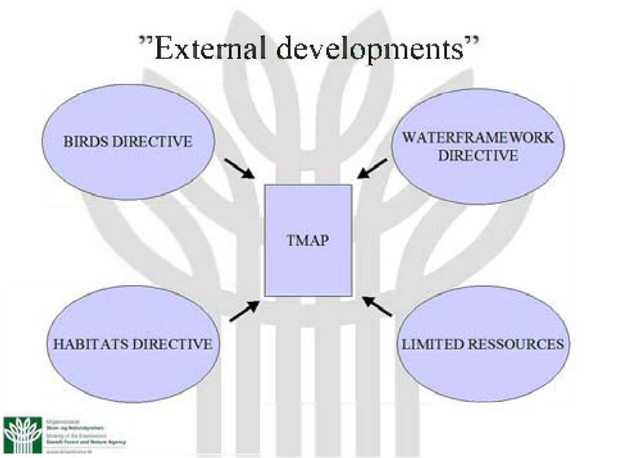

Figure 1. 'External developments' influencing the TMAP (Trilateral Monitoring and Assessment Program).

Thus - as a pre-conclusion - at the same time as developing the Wadden Sea monitoring programme during the last two decades, very important and significant changes have been made to the framework conditions for the Wadden Sea Cooperation, including its monitoring and assessment elements. This is the requirement from Brussels and from our ministries of finance. So, this is also becoming the fundamental challenge to the authorities responsible for monitoring administration and to managers.

EU monitoring and management challenges

EU has undertaken increasingly important developments which has consequences for Wadden Sea Cooperation with a special focus on monitoring and assessment.
During the last two decades, the EU has agreed on:

- First, the EC Birds Directive in 1979.
- Secondly, the EC Habitats Directive in 1992.
- And finally, the EU Water Framework Directive in 2000.

The designation process for the Habitat and Bird Directives has now almost been finalised in the Wadden Sea area and almost the entire area has been designated as EU Habitat and/or Bird protected areas – or as Natura2000 areas.

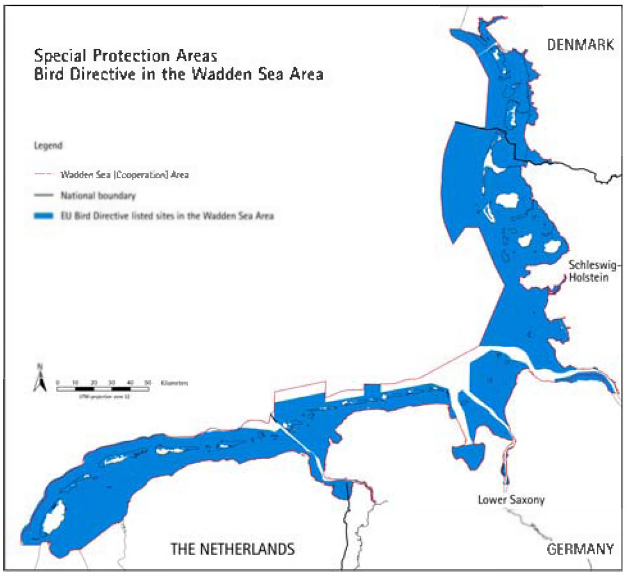

Figure 2. The cooperation area of the Wadden Sea with the Special Protection Areas (SPAs) indicated.

The designation of the special protected areas, and in addition of course also the designated habitat areas, is a new milestone as regards the future management of the Wadden Sea and the future monitoring requirements of the area.
The approach to nature protection within the EU is based on the following main aspects:

1) Immediate passive protection of the areas must be secured - that is, plans and projects, which may have significant, negative impacts on the species and natural habitats designated for protection in the areas, should not be initiated. Therefore, plans and projects cannot be approved without prior evaluation of the consequences.

2) Management of the areas must be active. Setting up specific targets for the state of the areas in order to safeguard or restore a favourable conservation status, and, moreover, requiring member states to implement the conservation measures required, in the form of management plans aiming at reaching the conservation targets set for the designated areas.

3) Monitoring and reporting to the European Commission on the state of nature, the measures taken and efforts made to comply with the directives. Monitoring is of course closely linked to the specific targets for the state of conservation of specific spe-

cies and natural habitats, thus illustrating whether the efforts made are sufficient.

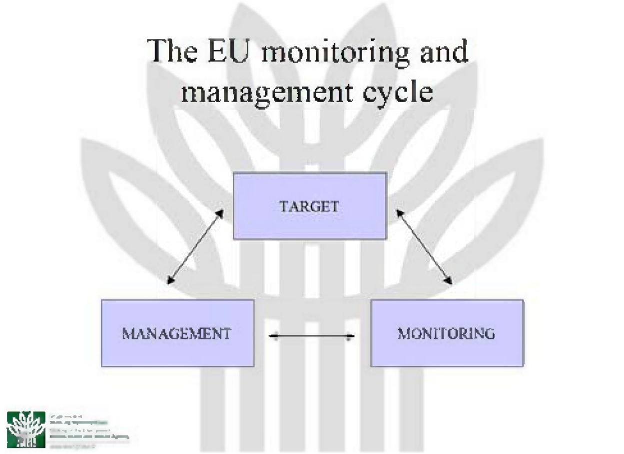

Figure 3. Principal elements in the EU monitoring and management cycle.

Therefore the EU directives provide a logical, systematic and transparent system for protection and active management, closely linked to monitoring. In fact, the same philosophy is represented in the "Policy circle" as presented by Karel Essink (2006) this afternoon. The basic approach is to set targets for the state of nature that specifically reflects the favourable conservation status for a given species or habitat. A monitoring programme is set up, with parameters that demonstrate the current status of conservation of the species or habitat. If necessary the specific efforts required to achieve the objectives are established through the management plans. Further the results of subsequent monitoring tell us the effect of the management plan and whether our efforts should be revised in order to achieve a favourable conservation status. Both the specific management plans and monitoring provide new know ledge, and, thus, enable us to adjust objectives in connection with the regular revisions. From an administrator point of view, this provides us with a logical, comprehensive management and monitoring system. This approach is also the basic philosophy of the Danish nature management model, and of the new Danish Environment and Nature Monitoring Programme. At the same time, it is closely linked to the targets and reporting obligations that Danish nature administrators must fulfil in accordance with the EU directives.

In Denmark it has been decided that the Natura 2000 Management plans for all the Danish Habitat sites – in total 254 – shall be finalised in 2009. That is the same deadline as the Water plans under the Water Framework Directive. Together, the three directives constitute a set of binding guidelines at EU level that apply also to the monitoring work done by the Trilateral Cooperation countries as the Wadden Sea as said now also has been designated as Bird and Habitats Directive areas. This is shown clearly in the presentations we have had today, and in the themes that will govern your discussions in the coming days.
What is important now is synergy and cohesion, in order to avoid duplication of work and waste of resources. Politically, the role of the EU is so important that, nationally, we have to focus more and more on the EU/Brussels context. This trend is underlined further by the changes in budgetary framework conditions which all three countries faced during the last couple of years. Both developments indicate that when we investigate and monitor, the goal must be crystal clear, and the results must have a useful purpose.

Danish experience

The Danish strategy for and approach to monitoring activities, should be based on a survey of demands, both administrative and management demands, as well as be related to operational targets. This will ensure that monitoring results clearly indicate whether the targets have been achieved, and whether developments are heading in a desirable direction. The purpose of monitoring is not only to collect data. The purpose is to satisfy the need for knowledge on the current state of the environment, about the development trend, and to see why developments might not be as expected.

A basic principle of monitoring should be to include parameters which we "need to know", in contrast to parameters which is "nice to know", and principle concerns also the TMAP.

I shall divide the following presentation into A) strategy and B) demands.

A) The monitoring strategy:
Our common Wadden Sea work aims at safeguarding nature and the good state of the environment. Therefore, our efforts only make sense if they help sustain these overall objectives. Monitoring as such will not enhance the state of nature and the environment, nor secure the habitats of the species involved. Meaningful monitoring is founded on scientific evidence, and is targeted towards political objectives and the need of administrators to know the state of nature and the environment.

The Danish monitoring is organised in accordance with the principle:"No monitoring without a goal". This means that, before monitoring is initiated, the proper objectives must be established. It is important that monitoring is viewed in a political-administrative context. However, to assess whether the goals are achieved, they must be operational. It is not operational to aim at a healthy and viable seal population without defining the meaning in terms of a measurable unit, for instance the number of animals per hectare, the number of puppies per year etc. Only this will enable us to see if the development is going in the right direction and assess if the objectives have been met.

B) Monitoring demands

In Denmark, monitoring obligations under the EU-directives rank highest on the list of priorities. There is a need for monitoring of the Wadden Sea and hinterlands, in order to meet the monitoring obligations under the Habitats Directive, the Birds Directive and the Water Framework Directive, and determine whether the targets have been reached – that is the targets set in the Wadden Sea Plan and in later agreements and in accordance with the directives mentioned. Setting targets is a political-administrative task. For the Wadden Sea, setting of operational targets will take place at the Ministerial Conference this autumn. Before that, administrative tasks must be coordinated among competent national authorities and the common secretariat. Existing targets should be revised and be made operational before the next Ministerial Conference. If they cannot be measured, they should be left out. Each country is responsible towards the European Commission for their implementation of the monitoring obligations under the directives, and each country is responsible for reporting to the Commission. Meeting the monitoring obligations is a national task, closely linked to operational objectives established at national level. When this has been done, we must analyse whether it is possible to further coordinate monitoring among the three countries. There may be a need for national methodologies, time series etc, as well as it may not be the same aspects that are relevant in the four Wadden Sea water districts.

The Habitats Directive sets out requirements for the favourable conservation status of a number of habitats and species. For habitats, this overall objective ensures that their range should be stable or increasing, that the specific structures and functions should be maintained, and that the habitats should hold viable populations of character species of a favourable conservation status. As regards species, the populations must be viable, their natural range should not be reduced, not even on a long-term basis, and the habitats of populations should be safeguarded.

The need for determining whether the objectives for a favourable conservation status are met shows the need for operational targets. For instance, for the natural habitats, measurable criteria must be used to assess the overall objectives of area, structure and function. Therefore, Denmark has been using a scientific approach to establish a number of technical criteria for a favourable conservation status, related to measurable parameters – structure, function, area etc. – thus allowing us to determine whether the conservation status is favourable, and to follow developments of important parameters, for instance impacts. This approach facilitates work to forecast future developments, as well as nature management. Later in this symposium, some presentations will give you a more detailed account of the habitat-monitoring element of the Danish monitoring programme.

As regards the Water Framework Directive, nature management must include the river basins of the waters. In the monitoring of the waters, impacts will constitute an important part of monitoring activities. For the Wadden Sea, this approach means that monitoring efforts should include the sources of impacts, and should thus also focus on areas outside the areas of co-operation. Monitoring under the Water Framework Directive must be relevant to the nature of problems. Therefore, some issues may be relevant to monitor in one water district, while other issues may be more relevant in another of the four Wadden Sea districts. Examples could be issues like tourism, agriculture and recovery of gas – which all cause different impacts on the Wadden Sea, but with differing intensities, and, thus, of differing importance and relevance for monitoring in the overall area of cooperation.

Conclusion

Especially in the new context of the Wadden Sea area having been designated as EU Habitat and Bird protected areas, the lessons learnt for monitoring demands for administration and managers of the Wadden Sea Cooperation are the following:

- resources are limited; therefore priorities and synergies are required,
- each Member States is responsible to the European Commission for implementing the EU directives, and therefore each country must establish operational objectives for their waters and nature areas, but often of course in a dialogue and coordination with neighbouring countries as is the case with the Wadden Sea
- each country must take responsibility for monitoring seen in relation to the monitoring obligations under the directives. This means that monitoring must be targeted towards the problems. Therefore relevant and necessary monitoring does not have to be the same in all Wadden Sea water districts,
- the objectives set for the Wadden Sea under the Ministerial Declarations must be operational and evaluated carefully to EU-obligations. They must of course not conflict with the objectives of the directives, but add when reasonable and cost effective and create synergy,

Figure 4. Main conclusions

- monitoring must help determine whether the objectives are fulfilled, and, if not, monitoring should give us a clue as to the reasons why the objectives are not fulfilled. To this end the QSR's are a very important tool,
- in order to be able to outline the overall impacts and state of the environment across the Wadden Sea, we need to coordinate monitoring efforts, taking into account the common targets set across the Wadden Sea,
- when the national monitoring under the directives have been implemented the possibilities for further coordination trilaterally should be analysed, thus allowing us to view additional issues, and finally
- the reporting format etc. for Wadden Sea monitoring should be aligned with the reporting formats used for EU reporting. We should avoid cost-intensive individual reporting formats etc., which may hamper synergy and pooling of data.

References

Crain, I. 2006. The role of TMAP data handling in supporting monitoring for EU Directives. – In Proceedings from the 11.th Scientific Wadden Sea Symposium, Esbjerg, Denmark, 4.-8. April 2005 (Laursen, K., Ed.); NERI Technical Report nr. 573: 37-43.

Essink, K. 2006. Trilateral Monitoring (TMAP) and Quality Status Report 2004 supporting conservation and management of the Wadden Sea. – In Proceedings from the 11.th Scientific Wadden Sea Symposium, Esbjerg, Denmark, 4.-8. April 2005 (Laursen, K., Ed.). NERI Technical Report nr. 573: 27-36.

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Trilateral Monitoring (TMAP) and Quality Status Report 2004 supporting conservation and management of the Wadden Sea

Karel Essink

Karel Essink 2006: Trilateral Monitoring (TMAP) and Quality Status Report 2004 supporting conservation and management of the Wadden Sea. In: Monitoring and Assessment in the Wadden Sea. Proceedings from the 11. Scientific Wadden Sea Symposium, Esbjerg, Denmark, 4.-8. April, 2005 (Laursen, K. Ed.). NERI Technical Report No. 573, pp. 27-36.

For any monitoring and assessment program the questions Why?, What?, Where? and How? are essential. It should be clear why monitoring is needed, or which purpose(s) should be served by monitoring. For the Trilateral Monitoring and Assessment Program (TMAP), such purpose is to periodically evaluate the agreed trilateral Targets as laid down in the Wadden Sea Plan of 1997. What had to be monitored to be able to evaluate these Targets was agreed upon by Denmark, Germany and The Netherlands by accepting the TMAP Common Package of parameters as suitable to provide the information necessary. The questions Where? and How? pertain to the sampling strategy and the analytical and statistical methods. In the case of TMAP, with different institutes and specialist groups performing in different sub-areas of the Wadden Sea, quality assurance and harmonization are other essential issues. An operational data exchange system completes the TMAP.

Periodic evaluation may or even should result in new or intensified management measures aimed at complying with the Targets set. If necessary, Targets need to be amended in response of advancing insight or changed policy priorities. As such, monitoring and assessment play an essential role in the so called 'policy cycle'.

In this contribution elements of the TMAP and evaluation results from the Quality Status Report Wadden Sea 2004 will be presented against the background of this policy cycle.

Key words: assessment, monitoring, policy cycle, targets, Wadden Sea

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Introduction

For the Trilateral Monitoring and Assessment Programme (TMAP) for the Wadden Sea as well as for any other monitoring programme the questions Why?, What?, Where? and How? are essential. It must be clear why monitoring is needed, or which purpose(s) is to be served by monitoring. For the TMAP, such purpose is the periodic evaluation of common Targets, trilaterally agreed between Denmark, Germany and The Netherlands and laid down in the Wadden Sea Plan (WSP 1997). What needs to be monitored to be able to evaluate these Targets, was agreed upon trilaterally by accepting the so called TMAP Common Package being a set of parameters suitable to provide the information necessary (Stade Declaration 1997). The questions Where? and How? pertain to the sampling strategy and the analytical and statistical methods. Sampling effort and observations need to be made in representative subsystems of the Wadden Sea ecosystem such as salt marshes, dunes, intertidal flats and subtidal habitats, and spread over its geographical range. Moreover, areas with known or expected human influence as well as reference areas with no or minimal human impact should be included (Colijn et al. 1995). In the case of TMAP, different institutes and specialist groups carry out the monitoring in the different sub-areas of the Wadden Sea. This makes harmonisation of methods and quality assurance essential issues. An operational data exchange system completes the TMAP without which the periodic assessment process would be seriously hampered.

The "Policy Cycle"

Periodic evaluation may or even should result in new or intensified management measures aimed at complying with the Targets set. If necessary, Targets need to be amended in response of advancing insight or changed policy priorities. As such, monitoring and assessment are essential in the so called "policy cycle" (cf. Winsemius 1986). Generally, in the Policy Cycle the following phases are distinguished: 1) problem identification and acceptance, 2) policy formulation, 3) policy implementation, 4) management, and 5) evaluation (Figure 1).

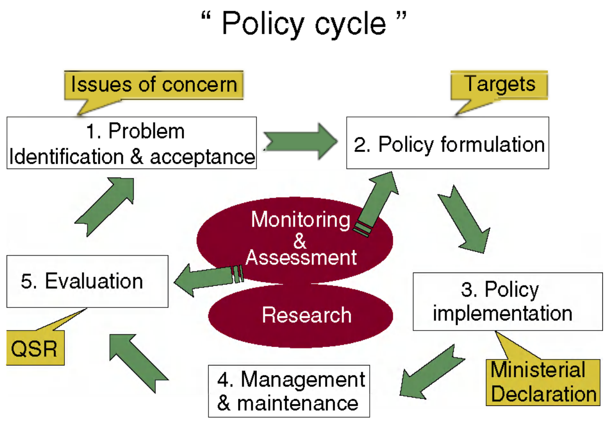

Figure 1. The 'Policy cycle' with the role of monitoring and assessment and of research in the trilateral Wadden Sea Cooperation

Problem identification and acceptance

This first phase in the policy cycle usually starts with an analysis of developments and trends which in the case of the international Wadden Sea may have consequences for e.g. its natural values, its attractiveness as living and recreational area for the human population, and its role as a turntable in large-scale ecological processes such as bird migration. Signals regarding developments and trends may come from society in general or from existing monitoring programmes. The accepted guiding principle for the trilateral Wadden Sea policy "to achieve, as far as possible, a natural and sustainable ecosystem in which natural processes proceed in an undisturbed way" dates back to 1991 (Esbjerg Declaration 1991, § 1).

Policy formulation

Once problems have been identified and accepted, ideas have to be developed - first of all on the political level - on what directions could be taken towards problem resolution. Essential is to properly define what goal should be reached and within what time frame. After preparation of a policy proposal – mostly by one or more directly involved ministries – the final decision is taken by the parliament. In the case of the Wadden Sea Cooperation, the current policy and its goals have been specified in the form of the Targets as laid down in the Wadden Sea Plan of 1997. This Wadden Sea Plan was agreed upon by the 8th Trilateral Governmental Conference on the Protection of the Wadden Sea held in Stade, Germany, 1997.

Policy implementation

In the national arena, the implementation of fixed policy usually is a co-production of central (government bodies) and decentralized authorities. This usually implies the formulation of management plans which go into more detail. Examples of these are the Beheersplan Waddenzee 1996-2001 (Rijkswaterstaat 1996) for the Dutch Wadden Sea, and the recent blue mussel management plan for the Wadden Sea of Lower Saxony (Staatskanzlei 1998). For the Wadden Sea the implementation of the agreed trilateral policy is laid down in the Ministerial Declarations of the periodically held Governmental Conferences. The Esbjerg Declaration of 2001 entails a listing of agreed actions and priorities for the trilateral cooperation in the period 2002-2005. The Schiermonnikoog Declaration (2005) will describe the actions and priorities for the next period.

Management

The factual implementation of the Ministerial Declarations becomes the responsibility of a great variety of higher and lower authorities and agencies, responsible for management as well as for maintenance of relevant legislation and regulations. Management usually has a strong sectorial approach; sometimes authorities work together, e.g., in the Dutch Wadden Sea (RCW 2004). Management activities may range from closure to the public of birds' breeding and roosting areas in the relevant season to the execution of nature restoration works in dunes and salt marshes.

Evaluation

The final and most essential phase of the policy cycle is the evaluation, in which is being checked to what extent the set targets have been met. Evaluation may also involve an assessment of the effective use of financial resources related to the reaching of the target.

A prerequisite for a good evaluation is the availability of relevant monitoring data. For the trilateral Wadden Sea cooperation this prerequisite is largely fulfilled by the Trilateral Monitoring and Assessment Programme (TMAP) and the institution of periodic Quality Status Reports. Evaluation may lead to a reconsideration of policy priorities and management measures, and even to a re-definition of targets.

Targets for the Wadden Sea

The trilateral conservation policy with respect to the Wadden Sea is directed towards conservation and/or restoration of all those habitat types that belong to a natural and dynamic Wadden Sea. For each of these habitat types a certain quality is envisaged to be reached by proper conservation and management measures.

Targets have been formulated for six habitat types, viz. salt marshes, tidal area, beaches and dunes, estuaries, offshore area and rural area, within which a number of sub-habitats were defined. Targets related to the chemical quality of water and sediment relate to all these habitat types. Supplementary targets have been agreed for birds (breeding as well as migratory species) and marine mammals (seals and harbour porpoise). The targets as included in the Wadden Sea Plan of 1997 (WSP 1997), together with their periodic assessment, play a central role in directing the trilateral conservation policy and related management.

The Trilateral Monitoring and Assessment Programme (TMAP)

A trilateral program, in short TMAP, is running to monitor the Wadden Sea, mainly aiming at providing data to be used for periodic assessment of the quality of the ecosystem of the Wadden Sea. Recognized "issues of concern" (climate change, input of pollutants, commercial fisheries, recreation and agricultural practice) were used as a guiding principle for parameter selection. Parameters were selected based on hypotheses regarding the various anthropogenic impacts on the ecosystem, and grouped to represent important habitats, organism groups and distinct species (TMAP 2000).

Table 1. The Common Package of TMAP parameters.

Chemical Parameters	**Habitat Parameters**
Nutrients	Blue Mussel beds
Metals in sediment	Salt marshes
Contaminants in blue mussel, flounder and bird eggs	Beaches and Dunes
TBT in water and sediment	
Oil rate of beached birds	
Biological Parameters	**Human Use Parameters**
Phytoplankton	Fishery
Macroalgae	Recreational activities
Eelgrass	Agriculture
Macrozoobenthos	Coastal protection
Breeding & migratory birds	**General (supporting) Parameters**
Harbour (= Common) Seals	

In 1997 a Common Package of parameters to be monitored in the TMAP was agreed upon (Stade Declaration 1997). An overview of the TMAP Common Package is presented in Table 1. The Trilateral Monitoring and Assessment Group (TMAG) has the task to implement the TMAP, which in essence is composed of several pieces of national monitoring programs.

An essential role within the TMAP, and more specifically the assessment process, is played by the TMAP data handling system. Four data units are being operated, viz. in Denmark, Schleswig-Holstein, Niedersachsen and The Netherlands. Structural, functional and organisational aspects as well as cost-effectiveness have recently been evaluated (Orbis 2004). The Trilateral Data handling Group (TDG), a subgroup under the TMAG, coordinates the necessary updates and amendments of the data units.

A process to optimise the TMAP and to further tune it to the requirements of EC Directives such as Birds Directive, Habitats Directive and Water Framework Directive, is presently ongoing.

Outcome of Evaluation (QSR 2004)

In the Wadden Sea Quality Status Report 2004 (Essink et al. 2005) a detailed account is given of the developments of various human activities in the Wadden Sea area and of the development of various ecosystem components (species, habitat forming species, habitats). An assessment of these developments provides an evaluation of the different targets as formulated in the Wadden Sea Plan (WSP 1997). In this chapter the main outcome of the target evaluation will be reviewed, and reference will be made to the policy cycle when appropriate. For detailed information the reader is referred to the actual 2004 Wadden Sea QSR. A review regarding hazardous substances (natural micropollutants and xenobiotics) is presented elsewhere in this volume (Bakker 2005). More and further detailed information on trends and developments is given in other papers of this volume.

Nutrients and eutrophication

Large inputs of nutrients such as phosphorus and nitrogen compounds were considered the cause of earlier eutrophication phenomena such as local oxygen deficiencies and blooms of the nuisance alga *Phaeocystis* sp. and green macroalgae (De Jong et al. 1999) or kills of fish and benthos such as occurred in the German Bight (Dethlevsen & Von Westernhagen 1983). Such phenomena were considered unacceptable for the Wadden Sea, which led to the target that the Wadden Sea "can be regarded as a eutrophication non-problem area". The prime action needed for development towards that target has since long been accepted as policy and regulations have been aimed at a considerable decrease of nutrient discharge through rivers debouching in the Wadden Sea (OSPAR 1997). The 2004 Wadden Sea QSR, with data up to 2002, shows that riverine discharges of nutrients have continued to decrease. The decrease in discharge of nitrogen, however, was slower than that of phosphorus. Also in the water of the Wadden Sea nutrients concentrations have decreased, as have phytoplankton chlorophyll levels.

How to evaluate the target? How do we know that eutrophication problems do not occur in the Wadden Sea any more? On the basis of the Comprehensive Procedure, developed for the OSPAR Convention Area (OSPAR 1997), Wadden Sea specific evaluation criteria were developed in a trilateral project (Van Beusekom et al. 2001). Autumn concentrations of ammonia and nitrite were considered suitable indicators of the eutrophication status of the Wadden Sea. Mainly based on these criteria, it is concluded that the target is not yet met. The Wadden Sea may still be a eutrophication problem area, with a higher degree of eutrophication in the southern than in the northern part, notwithstanding the observed declines in green macroalgal cover and in duration of spring blooms of *Phaeocystis*.

Oil pollution and sea birds

Oil pollution at sea mainly originates from ships, and to a lesser extent from oil drilling rigs in the North Sea. The Wadden Sea Plan does not have a specific target regarding oil pollution. For the OSPAR Convention Area, however, an Ecological Quality Objective (EcoQO) regarding the effect of oil pollution on the marine ecosystem was developed as an operational tool and target (Bergen Declaration 2002). And thanks to the so-called Trilateral Beached Birds Survey, now incorporated in the TMAP, data are available to evaluate this EcoQO, which reads "The proportion of oiled common guillemots among those found dead or dying on beaches should be 10% or less".

Although reported oil spills off the Dutch and German coasts have declined since the 1990s, and oil rates among beached birds have generally also decreased, the OSPAR EcoQO has not been met. Oil rates among birds found dead inside the Wadden Sea are lower than on the North Sea beaches of the Wadden Sea, indicating that oil pollution is mainly an external threat. Hopefully, the designation in 2002 of major areas of the Dutch, German and Danish Wadden Sea as Particular Sensitive Sea Area (PSSA) will contribute to a further decrease of oil pollution (Reineking 2002).

Salt marshes

These habitats can be found on the Wadden Sea islands and along the mainland shore. The vegetation of salt marshes is strongly determined by the duration of submergence by sea water per tide, and therefore by their elevation as result of natural or man-influenced sedimentation. As a consequence, different vegetation types can be discerned, intersected by meandering creeks or brushwood groynes and man-made drainage systems.

For Wadden Sea salt marshes three targets were formulated. Due to land reclamation and endikement the area of salt marshes in the Wadden Sea had decreased considerably (e.g. Dijkema 1987). Therefore, trilateral policy agreed on aiming at an increased area of natural salt marshes. Realising that a considerable part of the salt marshes was artificial due to land reclamation and their geomorphology and vegetation strongly influenced by man-made drainage systems, an additional target was formulated, aiming for increased natural morphology and dynamics, including natural drainage patterns, of artificial salt marshes. Finally, for artificial salt marshes an objective was set of obtaining a more natural vegetation structure.

Monitoring and evaluating changes in salt-marsh area or extent of artificial drainage do not seem too difficult a task. Practice, however, is less cooperative. In salt marshes processes of change take quite some time, changes becoming noticeable only after several years. Artificial drainage systems (ditches), when not maintained any more, have proven rather persistent, making it difficult to decide, for example, when an artificial ditch has developed to a naturally meandering creek. Proper evaluation can only be done when these changes are monitored with full coverage of all salt marshes, and a consistent time series of GIS data is available. In practice, good data are available for only a part of the salt marshes. These data show a general increase of area of (semi-)natural salt marshes and a decrease of maintenance of artificial drainage, thus indicating a development towards the target.

The target of an improved natural vegetation structure of artificial salt marshes poses a problem. Firstly, the vegetation structure is very much dependent on local geomorphological conditions. Secondly, it was not possible to give a precise description of the vegetation that can develop and serve as an evaluation criterion. Thirdly, as mentioned before, long-term data are limited, and not all older data can be translated to the common typology for salt-marsh zones and vegetation types that was recently developed within the TMAP. A precise evaluation of the third salt-marsh target can therefore not be given. In areas, however, where human use of salt marshes (e.g., livestock grazing) was reduced, a more natural vegetation structure did develop.

Tidal area

The Tidal area includes the intertidal flats and subtidal areas as well as the organisms living in its waters and sediments. Characteristic for these areas is the dynamics of hydrology and geomorphology, especially in the tidal inlets and their outer deltas.

Natural dynamics, no disturbance

"A natural dynamic situation in the Tidal area, and an increased area of geomorphologically and biologically undisturbed tidal flats and subtidal areas" are the formulations for the relevant targets of the Wadden Sea Plan. As a consequence, policy implementation and management, phase 2 and 3 of the 'policy cycle', could simply (?) focus on human activities reducing or disturbing this natural dynamics.

Natural dynamics of the sea shore is limited by coastal defence constructions. In the last five years there was no significant increase of these constructions.

Dredging of shipping channels, sometimes adjacent to intertidal flats, causes disturbance of natural sedimentation-erosion processes, and can therefore be judged as deviation from the target. Effects on the ecosystem, if of any significance at all, have not been documented, neither through monitoring nor research.

Intertidal flats are important as habitat for bivalves and other benthos. Bivalves prefer high flats of fine grained sediment for the settlement of their juveniles. Research by Delafontaine et al. (2000) has shown that as a result of progressive endikement, making the Wadden Sea narrower, wave energy increased causing a depletion of fine grained material. It has been made plausible that in the Dutch Wadden Sea intensive fishery for cockles and seed mussels has contributed to a reduction of the area of such high intertidal mud flats (Ens et al. 2004). Consequently, it can be concluded that no increase has occurred of the area of geomorphologically and biologically undisturbed tidal flats.

Land reclamation and shellfish fisheries can to some extent be blamed for the loss of preferred settling habitat of bivalves, but not completely. Climatic factors do also play a role. Analysis of long-term data sets for the westernmost part of the Dutch Wadden Sea shows that the more frequent occurrence of mild winters causes an enhancement of predation on newly settled bivalve post-larvae by shrimps and shore crabs (Beukema & Dekker 2005). This illustrates the importance of being able, through wise monitoring and research, to discriminate between anthropogenic impact and natural causes.

Biogenic structures

In the Tidal area, a few species occur that form specific biogenic structures. Examples are subtidal reefs of the polychaetous worm *Sabellaria spinulosa*, sea grass fields consisting of *Zostera marina* and *Z. noltii*, and beds of the blue mussel *(Mytilus edulis)*. For these biogenic structures the Wadden Sea Plan thrives for an increased area, and a more natural distribution and development.

Sabellaria reefs are extremely rare. Nowadays, one reef exists south of Amrum, and possibly two in the Jade. In former times, many more existed; it is not known what caused these to disappear. Monitoring of *Sabellaria* reefs is not included in the TMAP Common Package. This means that policy evaluation is completely dependent on fortuitous observations.

The long-term decline, since the 1930s, of sea grasses in the southern and central Wadden Sea seems to have come to a halt. And some slow recovery is evident in The Netherlands and Schleswig-Holstein. Yet, we still cannot speak of an overall increase in area and natural distribution of sea grass fields. The target of an increased area of *Zostera* fields is therefore not yet met in all sub-areas of the Wadden Sea.

When looking at the "policy cycle" it must be noted that in The Netherlands, having noticed the extremely slow recovery, evaluation resulted in an additional policy formulation viz. to investigate the possibility of re-introduction of sea grasses. This approach may contribute to sea grass recovery, especially in areas poor in natural seed production.

Regarding blue mussel beds there are conflicting interests of nature conservation and fisheries. Regulations have been implemented to safeguard the mussel bed habitat and at the same time allow mussel fisheries or mussel farming. Details of this are beyond the scope of this overview. A trilateral achievement was the new protocol for area measurement of intertidal mussel beds, which will enable future harmonized assessment.

As a result of consecutive spatfalls and of large areas having been without fisheries for seed mussels, a natural increase of intertidal mussel beds was observed during the 1990s. Since 1999, however, poor recruitment caused a decline.

Evaluation of data shows that in parts of the Wadden Sea the target of an increased area of natural intertidal mussel beds is met, but not yet so in other parts. Progress has been made with protection of young mussel beds at old or stable sites. At the same time, specialists realised that they do not yet fully understand the crucial spatfall process, nor the cause of regional differences in recruitment success. Such knowledge is indispensable for designing better management measures.

Concerning subtidal mussel beds, which are heavily exploited by mussel farmers, insufficient data is available to allow evaluation of the target.

Fish and shrimps

The occurrence of fish and shrimps, both not included in the TMAP, can be related to two more general Wadden Sea targets, viz. 1) an increased area of geomorphologically and biologically undisturbed tidal flats and subtidal areas, and 2) a favourable food availability for migrating and breeding birds.

With regard to the latter target, there is no evidence of general food shortage among fish and shrimp eating birds. With respect to the former target it needs to be clarified whether there is any causal relationship between the recorded offshore shift in the distribution of juvenile flatfish, especially dab and plaice, and the area and quality of intertidal flats and subtidal areas. This signal from national monitoring data deserves to be followed up by adequate research.

An evaluation regarding pelagic and migratory (diadromous) fish is hampered by absence of appropriate monitoring. Here a change in the TMAP is necessary with a view to the implementation of the EU Water Framework Directive in transitional waters (= estuaries).

Beaches and dunes

The Wadden Sea Plan targets regarding beaches and dunes refer to natural dynamics, natural vegetation succession and favourable conditions for birds. The latter target (on birds) will be dealt with in the section on breeding birds.

Natural dynamics

Due to the absence of both criteria and comparable data it is not possible to evaluate the dynamics of beaches and dunes. In fact, this is a shortcoming already in the beginning of the "policy cycle". Within the TMAP no parameters have been developed to enable an evaluation of the target. What can be said, however, is that natural dynamics of beaches has increased where coastal defence activities were stopped, for instance at head- and tail ends of islands.

Natural dynamics of dunes has increased only locally. The area with embryonal dunes, white dunes and primary dune slacks has not increased. Remnant coastal defence structures (e.g. sand dikes) still are an impediment to natural dynamics.

Complete natural vegetation succession

With regard to the target of an increased presence of a complete natural vegetation succession, it must be concluded that target has not been reached. About two-thirds of the dune areas consist of mid-successional dune type and other vegetation types are not present or show further decline. On some islands, species rich dune slack vegetations have degraded due to groundwater extraction, causing an accelerated succession to drier vegetation types. In some areas accelerated succession is remedied by traditional-type management measures restoring successional processes and species rich habitats.

How to proceed?

The Wadden Sea QSR reveals that too little specific data is available to enable a proper evaluation of the first two targets. On the one hand side, the targets have not been elaborated to objective and quantitative parameters to be monitored. The newly developed TMAP classification of dune types certainly will provide a helpful tool in this respect. On the other, there is a need to reconsider and redefine the trilateral targets against the background of (1) the high recreational pressure on the coastline, (2) the EU Birds- and Habitats Directives, and (3) sea level rise and its concomitant intensification of coastal defence.

Estuaries

Estuaries have since long attracted human population and its various activities, most of these being related to trading overseas as well as inland. As a consequence, industrial development boosted, and connected with this also shipping. Many estuarine habitats have disappeared or their extent is greatly reduced. As a counterweight to these human pressures the Wadden Sea Plan states as trilateral policy that valuable parts of estuaries will be protected and river banks will remain and, as far as possible, be restored in their natural state.

Few estuaries are present in the Wadden Sea, of which the Varde Å estuary has largely retained its natural characteristics. For reason not well known, not much effort was put into translating this rather broadly formulated target into operational parameters for monitoring. Hydrology of estuaries has been monitored rather intensively, without doubt because of its significance for shipping. So we know that increased deepening of shipping channels has changed high tide and low tide water levels and current velocities. Continuous dredging and dumping of the dredged material elsewhere is necessary.

Speaking of valuable parts, progressive human pressure has resulted in loss of tidal flats and brackish-water habitats. So called 'Red List' species, signalling their endangered status, do still occur in the estuaries of Elbe, Weser and Ems, which indicates that valuable habitats do still exist, but their extent is hardly known (cf. Von Nordheim et al. 1996). The larger estuaries of the Wadden Sea do not meet the target, as is concluded also in the relevant Water Framework Directive Reports of 2005 (EG-WRRL 2004a, b, c, 2005).

In terms of the 'policy cycle' policy implementation (phase 2) for estuaries has not yet started. Apparently, management plans for the larger Wadden Sea estuaries have not yet been drafted or have not well been communicated trilaterally. Possibly, there is also a lack of essential information as a basis to design such management plans. The EU Water Framework Directive, urging the design of River Basin Management Plans, may put new life into the implementation of this Wadden Sea target.

Offshore area

The Offshore area is positioned seaward of the Wadden Sea islands, extending to the 3 mile limit, but including the Conservation Area beyond this limit. This seaward limit is artificial, not functional. Three targets apply to this area.

Natural morphology

Apart from coastal defence works on the Wadden Sea islands (e.g. sand nourishments on the foreshore, cross-shore dam at Texel) no evidence has become available regarding major negative developments in natural dynamics of the geomorphology of this area.

Food availability for birds

Important stocks of the bivalves *Spisula subtruncata* and *S. solida* occur in the Offshore area. These bivalves are a major food resource for diving duck species such as common scoter and eider. For eider they form an escape in case of adverse food conditions inside the Wadden Sea, e.g. due to severe winter or intense shellfish fishery. Therefore, the fishery on *Spisula* should be carefully managed in relation to conservation of these bird species.

Viable stocks of marine mammals

The Offshore area constitutes a part of the living range of harbour seal, grey seal and harbour porpoise, which do not only use the Wadden Sea proper but also large parts of the North Sea (see Marine Mammals).

Birds

Breeding birds

For more than 30 bird species, the Wadden Sea area is important as breeding area. Breeding habitats are present in salt marshes, dunes, pastures and on beaches. Two targets especially apply to breeding birds, viz. 1) a favourable food availability, and 2) a natural breeding success.

Food availability - The breeding populations of common eider (with more than 75% in the Dutch Wadden Sea), oystercatchers and probably also herring gull have declined mainly in the Dutch Wadden Sea. This is considered an effect of intense shellfish fisheries notwithstanding the management measure of having areas closed for fisheries and reserving certain amounts of cockle and blue mussel stocks for birds (Ens et al. 2004).

Breeding success - Measures aimed at protection of breeding sites of the little tern have proven successful. The significance of the beaches as breeding habitat for bird species such as great ringed plover and Kentish plover has further decreased. As this was already concluded in the previous Wadden Sea QSR (De Jong et al. 1999) it must be concluded that management measures have not been effective at all.

Increased predation pressure by mammalian predators, e.g. red fox, on the mainland caused some bird species to shift their breeding numbers from the mainland to the islands. May be, action is needed to protect the island breeding habitats by keeping mammalian predators away.

Migratory birds

In 22 out of 34 water bird species numbers have experienced declines over 1992-2000. This is an alarming and new development since the 1999 Wadden Sea QSR.

Favourable food availability and sufficiently large undisturbed roosting and moulting areas are the two major targets relevant for migratory birds.

Food availability - What can be said about food availability? Of the 22 species showing a decreasing trend, 19 were dependent on feeding on benthos, incl. bivalves, for 'fast refuelling' during their migration to the breeding and wintering areas. This is an indication of non-favourable food availability, although other risk factors may play a role. For the migratory bird species within this group and specialising in molluscs (e.g. eider, oystercatcher, knot and herring gull), food availability was impaired due to shellfish fishery. In conclusion, the target is not met.

In contrast, for herbivorous species (e.g., dark-bellied brent goose, Eurasian wigeon, barnacle goose) food availability seems not to be limited.

Undisturbed roosting and moulting - For three species important moulting areas exist in the Wadden Sea and offshore zone viz. for shelduck, common scoter and common eider. Protection of moulting shelduck has been improved through voluntary agreements with different user groups (e.g., fishermen, yachtsmen) aimed at avoidance of disturbance during the moulting season.

Although most high tide roosts are situated in well protected areas, disturbances do still occur due to outdoor recreation. Moreover, some species prefer high tide roosts on agricultural land, which are not well protected or not protected at all. Therefore, the target is not satisfactorily met.

Marine mammals

The common target for each of the most important marine mammal species in the Wadden Sea area is to have viable stocks and a natural reproduction capacity. Monitoring of harbour and grey seal in the Wadden Sea is organised in the framework of the Seal Management Plan 2002-2006 (SMP 2002) under the Bonn Convention. The implementation of the Seal Management Plan is done by the trilateral Wadden Sea cooperation.

Harbour (= common) seal

The harbour seal population that quickly recovered from two successive PDV-epizootics can be considered viable having a satisfactorily high reproduction capacity.

New is knowledge obtained through satellite transmitters mounted onto harbour seals, showing that these animals use the North Sea to a much greater extent than realised before. The reason for this is not yet investigated.

Grey seal

Grey seals have increased in the Dutch and Schleswig-Holstein part of the Wadden Sea. There are signs of expansion of the population to other parts of the Wadden Sea (e.g. Borkum Riff, Norderney). Although reproduction has increased, a major part of the population increase can be attributed to influx from populations along the east coast of Great Britain.

Protection of grey seals is not yet optimally organised, and the target cannot be evaluated with satisfaction due to insufficient data. Grey seal monitoring is not included in the TMAP Common Package.

Harbour porpoise

The Offshore area and adjacent North Sea, especially off Schleswig-Holstein, is important for harbour porpoise. Dedicated trilateral (TMAP) surveys with harmonized methods do not exist. As a consequence, the target cannot be evaluated due to insufficient information.

Discussion and Conclusions

New information, as made available in the 2004 Wadden Sea QSR, provides answers to questions and allows evaluating the targets of the Wadden Sea Plan. There are, however, several limitations.

As stated above, not all Wadden Sea Plan targets are operational, meaning that not all targets have been translated into well defined parameters to be monitored. In most cases, the TMAP Manual (TMAP 2000) provides such a parameter definition. In other cases, such as with respect to the natural dynamics of beaches and dunes, operational monitoring objectives have not yet been formulated.

Another aspect to be discussed is the mere absence of quantifiable targets. Most targets refer to an increase (e.g. area of sea grass fields) or a favourable situation (e.g. food availability for birds) without any further specification. Of course, policy makers wanted the targets to be that general, that vaguely formulated, allowing the partners in the Wadden Sea Cooperation some room for manoeuvre. The drawback of this is that when the time has come for evaluation the policy makers see themselves dependent of the opinions of various specialists regarding the targets being met or not. And specialists may not always be fully objective. The consequence would be to reconsider targets in such a way that they can easily be translated in objective and quantifiable monitoring objectives.

Having said that, and assuming that a nice set of well defined monitoring parameters has been agreed, is it then wise to only monitor those parameters that can tell us whether a certain quantified target is met? For example, a total area of sea grass fields with more than 10% cover of "X" thousand hectares, with a natural distribution over the different sub-regions of the Wadden Sea as x : y : z : ....? My answer is "no". It is of utmost importance to be able to discriminate between changes due to human activities, that directly or indirectly influence the target, and changes due to natural processes, e.g. climatic change. Moreover, the Wadden Sea is a wide open system, being influenced from land as well as from the North Sea. So, the policy makers must be prepared to fund monitoring programs that provide both these options.

New information usually also brings new questions to be answered. This is because we are working with a simplified notion of reality, in policy making, in management as well as in research. This Wadden Sea QSR comprises quite a number of recommendations for further research to fill gaps in our knowledge of the functioning of the Wadden Sea ecosystem. Among these gaps are apparent functional differences between northern and southern parts of the Wadden Sea, such as in the case of nutrient concentrations in relation to decreased discharges from the major rivers. An improved understanding of such regional differences will contribute to a better protection of the Wadden Sea.

The trilateral cooperation is not the only player in the Wadden Sea arena. The policy world around the Wadden Sea is changing. Most important in this respect are the European Directives, such as Birds, Habitats and Water Framework Directives. All these include obligations for nations, and in the case of the Water Framework Directive at the sub-nation scale of River Basin Districts. In comparison, the transnational character and experience of the Wadden Sea Cooperation is of particular added value. The Guiding Principle of the trilateral Wadden Sea policy "to achieve, as far as possible, a natural and sustainable ecosystem in which natural processes proceed in an undisturbed way" (Esbjerg Declaration 1991) remains valid.

References

Bakker, J.F. 2005: Monitoring of contaminants in the Wadden Sea (this volume).

Bergen Declaration 2002: Fifth International Conference on the Protection of the North Sea, 20-21 March 2002, Bergen, Norway. - Ministry of the Environment, Oslo, Norway.

Beukema, J.J. & Dekker, R. 2005: Decline of recruitment success of cockles and other bivalves in the Dutch Wadden Sea: possible role of climate change, predation on postlarvae and fisheries. - Marine Ecology Progress Series 287: 149-167.

Colijn, F., Dankers, N. & Jensen, A. 1995: The need for reference areas for scientific research and (nature) management. - Wadden Sea Newsletter 1995-2:17-19.

De Jong, F., Bakker, J.F., van Berkel, C.J.M., Dankers, N.M.J.A., Dahl, K., Gätje, C., Marencic, H. & Potel, P. 1999: Wadden Sea Quality Status Report 1999. - Wadden Sea Ecosystem No. 9. Common Wadden Sea Secretariat; Trilateral Monitoring and Assessment Group, Quality Status Report Group. Wilhelmshaven, Germany.

Delafontaine, M.T., Flemming, B.W. & Mai, S. 2000: The Wadden Sea squeeze as a cause of decreasing sedimentary organic loading. - In: Flemming, B.W., Delafontaine, M.T.& Liebezeit, G. (Eds.); Muddy coast dynamics and resource management. Elsevier Science, pp.273-286.

Dethlefsen, V.& von Westernhagen, H. 1983: Oxygen deficiency and effects on bottom fauna in the eastern German Bight 1982. - Meeresforschung 30(1): 42-53

Dijkema, K.S. 1987: Changes in salt-marsh area in the Netherlands Wadden Sea after 1600. - In: Huiskes, A.H.L., Blom, C.W.P.M. & Rozema, J. (Eds.); Vegetation between land and sea. Junk, Dordrecht: 42-49

EG-WRRL 2004a: Bestandsaufahme Flussgebietseinheit Weser 2005. Teilraum Tideweser, 5. Entwurf 04.10.2004.

EG-WRRL 2004b: Bericht über die Umsetzung der Anhänge II, III und IV der Richtlinie 2000/60/EG im Koordinierungsraum Tideelbe (B-Bericht).Vorlage zur Elbe-Ministerkonferenz am 9. Dezember 2004.

EG-WRRL 2004c: Umsetzung der EG-Wasserrahmenrichtlinie - Landesinterner Bericht zur Analyse der Belastungen auf die Gewässer in der Flussgebietseinheit Eider. AB/2004.610W, pp.10.

EG-WRRL 2005: Bestandsaufnahme zur Umsetzung der EG-Wasserrahmenrichtlinie. Bearbeitungsgebiet Ems-Dollart-Ästuar. Deutsch-Niederländische Grenzgewässerkommission, Unterausschuss G, Entwurf 07.03.2005.

Ens, B.J., Smaal, A.C.& de Vlas, J. 2004: The effects of shellfish fishery on the ecosystems of the Dutch Wadden Sea and Oosterschelde; Final report on the second phase of the scientific evaluation of the Dutch shellfish fishery policy (EVA II). Alterra-report 1011. Alterra, Wageningen.

Esbjerg Declaration 1991: Man and Wadden Sea. Ministerial Declaration of the 9th trilateral governmental conference on the protection of the Wadden Sea, Esbjerg, October 31, 2001. Common Wadden Sea Secretariat, Wilhelmshaven, Germany.

Esbjerg Declaration 2001: Sixth Governmental Wadden Sea Conference, Esbjerg, 1991. Ministerial Declaration, Seals Conservation and management Plan, Memorandum of Intent, Assessment Report. Common Wadden Sea Secretariat, Wilhelmshaven, pp. 152

Essink, K., Dettmann, C., Farke, H., Laursen, K., Lüerßen, G., Marencic, H. & Wiersinga, W. (Eds.) 2005: Wadden Sea Quality Status Report 2004. - Wadden Sea Ecosystem No.19. Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group, Wilhelmshaven, Germany.

Orbis 2004: Evaluation of TMAP data handling for the trilateral Wadden Sea Cooperation. – The Orbis Institute, Ottawa, Canada, September 2004, pp. 42 & 7 Annexes.

OSPAR 1997: OSPAR Agreement 1997-17: The common procedure for the identification of the eutrophication status of the OSPAR Maritime Area. - OSPAR Commission.

RCW 2004 : Maatregelenprogramma Waddenzee 2004-2009 waarin opgenomen Handhavingsprogramma Waddenzee. - Regionaal Coördinatiecollege Waddenzeegebied, Leeuwarden.

Reineking, B. 2002: The Wadden Sea designated as a PSSA. - Wadden Sea Newsletter 2002-2: 10-12.

Rijkswaterstaat 1996: Beheersplan Waddenzee 1996-2001. - Rijkswaterstaat, Directie Noord-Nederland, Leeuwarden.

Schiermonnikoog Declaration (2005): Tenth Governmental Wadden Sea Conference, Schiermonnikoog, The Netherlands, November 3, 2005. (in prep.)

SMP 2002: Conservation and Management Plan for the Wadden Sea Seal Population 2002-2006, including Additional Measures for the Protection of the Grey Seal in the Wadden Sea. - In: Ministerial Declaration of the 9th Trilateral Governmental Conference on the Protection of the Wadden Sea, Esbjerg, October 31, 2001, Annex 1 (English version). Common Wadden Sea Secretariat, Wilhelmshaven, Germany: 25-37.

Staatskanzlei 1998: Miesmuschelmanagement-plan. - Staatskanzlei Niedersachsen.

Stade Declaration 1997: Ministerial Declaration of the Eighth Governmental Conference on the Protection of the Wadden Sea. Stade, October 22, 1997.

TMAP 2000: TMAP Manual, version June 2000. - Common Wadden Sea Secretariat, Wilhelmshaven.

Van Beusekom, J.E.E., Fock, H., de Jong, F., Diel-Christiansen, S. & Christiansen, B. 2001: Wadden Sea specific eutrophication criteria. - Wadden Sea Ecosystem 14: 1-115.

Von Nordheim, H., Norden Andersen, O. & Thissen, J. (Eds.) 1996: Red List of biotopes, flora and fauna of the trilateral Wadden Sea area, 1995. - Helgoländer Meeresuntersuchungen 50, Supplement.

Winsemius, P. 1986. Gast in eigen huis: beschouwingen over milieumanagement. Samson H.D. Tjeenk Willink, Alphen a/d Rijn. 227 pp.

WSP 1997: Trilateral Wadden Sea Plan. - In: Ministerial Declaration of the Eighth Trilateral Governmental Conference on the Protection of the Wadden Sea. Stade, October 1997, Annex 1. Common Wadden Sea Secretariat, Wilhelmshaven, Germany.

The Role of TMAP Data Handling in Supporting Monitoring for EU Directives

Ian K. Crain

Crain, I.K. 2006: The role of TMAP Data Handling in Supporting Monitoring for EU Directives. In: Monitoring and Assessment in the Wadden Sea. Proceedings from the 11. Scientific Wadden Sea Symposium, Esbjerg, Denmark, 4.-8. April, 2005 (Laursen, K. Ed.). NERI Technical Report No. 573, pp. 37-43.

The TMAP data handling system has been developed and implemented in a series of stages spanning over ten years. The system was evaluated in 2004 as the TMAP data handling reached a very critical stage - the long-sought milestone of harmonized data availability, effectively achieving the Esbjerg Declaration target of having an *"operational data handling system"*.

TMAP Data Handling was designed to provide science-based monitoring, that is standardised time series data of observational variables. Such consistent long-term monitoring is essential to conducting assessments of status, conditions, and trends to support reasoned decision-making, and importantly, to monitor the on-going effects of decisions and actions. Its enormous value comes from it being harmonized across the three countries, and being consistent in quality and meaning over a long time frame – in some cases as long as 25 years – allowing for an ecosystems view of the Wadden Sea as a whole.

Although originally designed to address the specific Issues of Concern, the TMAP data and data handling system have great potential to support various aspects of obligations of nations to assess and report to EU Directives. Of particular relevance are the Habitats, Birds and Water Framework Directives. Improvements in the TMAP Data Handling would enable the extraction of information from the TMAP time-series in forms suitable for the development of consolidated indicators, and to support quantitative and qualitative assessments. While necessary, the TMAP monitoring data is not sufficient to meet all requirements. It will always be necessary to augment the time-series with the results of research studies, and socio-economic data.

The possibility exists to integrate TMAP-DH more closely with the EEA Reportnet process. Whatever the technological evolution, there would still remain a strong need for countries to coordinate their approaches to implementation of the Directives, including for site designation, design of management plans, River Basin designation, and monitoring regimes, and for a TMAP data Handling System that ensures harmonisation and can query, process and analyse the data to serve the objectives of the CWSC. Elimination of the time-series of Wadden Sea scientific monitoring observations would severely handicap decision-making regarding the Wadden Sea ecosystem.

Key words: Data handling, decision-making, EC Directives, environmental monitoring, information systems

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Introduction

It is fundamental to any decision-making process to have a base of consistent information to enable rational decision- making and to assess the effectiveness of decisions and resulting actions. A generic decision-making process involves a number of steps all of which need to be informed by relevant data sources (Figure 1).

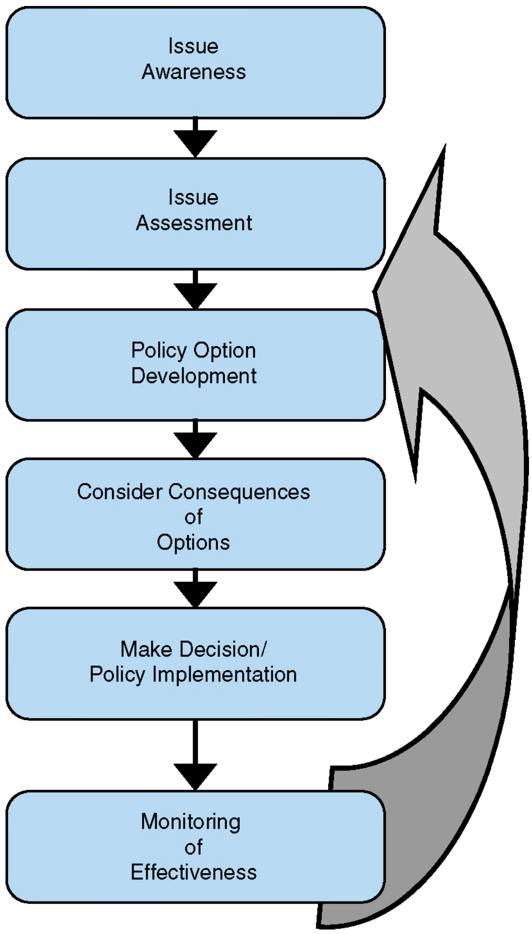

Figure 1. Generic Decision Making Process

It was recognised at an early stage of the Common Wadden Sea Cooperation that scientific monitoring of the state of the Wadden Sea ecosystem was essential. In the 1982 Joint Declaration on the Protection of the Wadden Sea, the Netherlands, Denmark and Germany recognized:

"their responsibilities for the conservation of the ecosystem and the biological values of this region and its components as well as natural beauty" and agreed to

"consult with each other in order to coordinate their activities and measures to implement … legal instruments with regard to the comprehensive protection of the Wadden Sea region as a whole including its fauna (marine terrestrial and avian) and flora with special emphasis on … seals and waterfowl"

The Declaration marked the beginning of considerations of joint monitoring of the environment of the Wadden Sea. It was also recognised that a "data handling" system was an essential component for managing the monitoring data across the area as a whole, hence datasets harmonised between the three countries. The general principles and outline of a trilateral joint monitoring program, including the associated data management, were adopted in 1993.

The TMAP Data handling system (TMAP-DH) was developed and implemented in a series of stages over 10 years, commencing with an EC-funded demonstration pilot project called DEMOWAD. During that time, a common data model and practical harmonisation procedures were agreed, and TMAP Data Units were established in each of the three countries (2 in Germany for a total of 4 locations). At each of the four Data Units, a relational database has been established following the common model, national time-series data have been entered for many of the Common Package of parameters, and most importantly, a common Internet-based data access service has been developed making the data available for download. By late 2004 TMAP Data Handling reached a very critical stage - the long-sought milestone of harmonised data availability, effectively achieving the Esbjerg Declaration target of having an "operational data handling system". At that point it was highly appropriate to invite an evaluation. This was conducted by the Orbis Institute and resulted in a report of findings (CWSS 2004) including 29 recommendations for future steps.

Principles of environmental monitoring

It has been recognised for many decades that systematic long-term monitoring of environmental conditions is essential for effective decision-making (Figure 1) on conservation and sustainable development. Scientifically based data should at best serve three main purposes – creating an understanding of cause-and-effect relationships (hence informed decisions on mitigation of problems), early warning of potential problems (enabling timely decisions on avoidance measures), and assessment of the impact of decisions (enabling adjustment and refinement).

These purposes lead to the key characteristics required of monitoring data (and data handling):

- Scientific validity – systematic collection, valid measurement methods
- Continuous time series on a consistent basis
- Harmonised data so that they can be aggregated and integrated
- Interpretable in a meaningful way.

Long term monitoring of the environment is now frequently undertaken by governmental bodies at all levels, from local community to global, and by NGOs, and through volunteer programs. At the global level, monitoring was one of the early cornerstones of UNEP and its "Earthwatch" concept. Shortly after the inauguration of UNEP, the Global Environmental Monitoring System (GEMS) was formed and became one of the primary Programme Activity Centres of UNEP. GEMS had components that monitored air, water, radiation, human health (as related to the environment) and terrestrial ecosystems. The latter spawned the Global Resource Information Database (GRID) project that evolved into a number of regional centres using remote sensing and Geographic Information System (GIS) technology to accumulate information on land cover and change, and to provide capacity building at regional and national levels.

Many countries have introduced national environmental statistical systems, and various approaches to State-of-the Environment monitoring. Many of the international conventions explicitly recognise the need for monitoring, and there are several international initiatives such as the Global Environmental Outlook ("GEO Process") and the Millennium Ecosystem Assessment, as well as regional efforts such as the "Environment for Europe" process that are currently active.

In spite of the known benefits and current global activities, long term ecological monitoring is not well established overall, nor consistently funded and supported. In the 1990s, for instance, UNEP-GEMS was dismantled and devolved in part to more specialised agencies, with the formation of three linked "observing systems" – Global Ocean Observing System (GOOS), Global Climate Observing System (GCOS) and the Global Terrestrial Observing System (GTOS). The first two of these have clear focus – GOOS under IOC, and GCOS under WMO linking to Climate Change Convention activities. GTOS (which would include coastal marine monitoring such as TMAP) is less focussed and weakly supported. One specific GTOS product is the Terrestrial Ecosystem Monitoring Site (TEMS) database. This is a very loosely connected network with no effective harmonisation or standards and relies entirely on the voluntary participation of the site managers.

Many national monitoring programmes have started and then failed to continue, and examples of regional monitoring programmes are rare. Lack of funding and support for monitoring is a universal problem. Some of the issues and problems are:

- Lack of universal agreement on what needs to be monitored
- Underestimation of the effort required to achieve harmonisation
- Underestimation of the effort required to organise, manage and provide access to the information base
- Dependency on NGOs and volunteers for data collection
- Lack of demonstrable immediate value – that is, monitoring not being tied to a specific issue of concern or question of interest to legislators
- Disconnection from high-level indicators – it is often unclear how the 'scientific" data should be interpreted, and how data could or should be aggregated into useful indicators.

The lack of support forces long-term monitoring programmes to "partner" in an opportunistic (not necessarily strategic) way, often with minimal resources to introduce the standards needed for long-term consistency, or to develop appropriate information systems for information analysis, synthesis, and communication. This limits the value of the information that has not been collected with a particular goal in mind, or is assembled from programme information and research studies that have no integrated systematic framework. This results in circularity – these weaknesses in the monitoring data quality further reduce the potential for support.

TMAP, in spite of recognised value, is clearly not immune from these common issues, and the resource expenditures necessary to continue monitoring and data handling are being questioned.

Relevant findings of the TMAP-DH evaluation

It is not the purpose of this paper to repeat the extensive findings and recommendations of the TMAP Data Handling Evaluation (CWSS 2004), rather to focus on issues relevant to the role of TMAP-DH with regard to the EC Directives. Some of the more relevant findings follow.

Data Handling Design is based on hierarchical logic

The Evaluation confirmed that TMAP Data Handling is correctly mandated and fully relevant. To trace the analysis in reverse order:

- A "data handling system" is essential to organise and manage the quantitative data resulting from monitoring activities.
- Monitoring data is recognized as being the "core" and the selected 28 parameter groups are agreed to be appropriate and necessary.
- The monitoring activities are essential to assessment of the achievement of the established Ecological Targets mandated in the Wadden Sea Plan.
- The Wadden Sea Plan is a direct response to the primary objectives of the Cooperation with regard to "conservation of the ecosystem" and "protection of the Wadden Sea area as a whole".

The logical flow is therefore correct – the Ecological Targets evolve from identification of Issues of Concern; the monitoring programme was developed to gather the required data; parameters have been selected to help assess the Targets; the data handling system was developed to manage the selected parameter data.

This is a very positive finding. The monitoring, data handling and reporting regimes of the majority of Multinational Environmental Agreements (MEAs) emphasise administrative compliance (existence of action plans and legal transpositions), and/or collect data on the basis of what is easily available, traditionally collected, or other ad-hoc approaches – rather than identifying monitoring data needs related to identified issues of concern and agreed objectives or targets. TMAP and TMAP-DH are remarkable in this regard; there are few other examples worldwide where such a logical top-down approach has been applied (Olsen & Nickerson 2003).

Values of TMAP Data

The successful harmonisation, and long term time-series are two key characteristics that make the TMAP data sets much more valuable than the national datasets from which they are derived. Monitoring is at the core of the Trilateral Wadden Sea Cooperation; it is recognised as essential to being able to treat the ecosystem as a whole. The values that TMAP monitoring data can provide therefore include:

- Support for research studies
- Support for national decision-making and policy development
- Support for public awareness and NGO activities
- Support for conservation management at the local level (e.g. national park) in an ecosystem context
- Supporting data for assessment against the Ecological Targets (e.g. the QSRs)
- Support for other Wadden Sea assessments as required
- Rapid identification of abnormal or alarming situations
- Enabling of joint projects, actions and harmonised legislation
- Facilitation in meeting international conservation obligations
- Raw data for aggregation to assist with national, European and international reporting obligations.

The logical top-down process by which TMAP parameters have been selected, and harmonisation measures developed and implemented (and documented in the TMAP Manual, CWSS 1997) ensure that the scientific data collected is relevant to the issues and the decision-making process for the Wadden Sea ecosystem. It should be emphasised that TMAP time-series monitoring data is necessary, but not sufficient, for assessment of the Targets – there will always be a need for other kinds of observations (such as localised research studies on processes) which need not be, or should not be "monitored" in multiple locations, or at regular specified time intervals.

Of the list of values or uses given above perhaps only the first three could be achieved without the TMAP data handling, indicating that the added effort of harmonisation provides many (potential) benefits – benefits that are directly connected to the objectives of the TWSC, as well as potential value-added benefits.

"At the risk of being repetitive, much of the value of the TMAP data comes from them being collected in systematic programmes, with harmonised methods consistently over a continuous period of time – so that baselines can be established and trends extracted and tested for significance. This contrasts sharply with the limited value of equally large collections of data that might be assembled from disparate research studies of unsystematic observations over periods of time, where interpretation is difficult due to unrepresentative sampling methodologies and unknown amounts of observer bias. TMAP data has been specifically selected from systematic programmes with known methodologies and sampling protocols, and that process of selection and harmonisation has involved considerable investment. While, as mentioned above, the data must be augmented from time to time by specific research studies, such one-time investigations cannot be a substitute for the time-series data when making assessments and consequent policy decisions and actions." (CWSS 2004 p. 30).

TMAP Data Handling and the EC directives

While the original conception of TMAP-DH was to support the Wadden Sea Plan and inform the TWSC in decision-making concerning the conservation of the Wadden Sea ecosystem as a whole, one of the directions of evolution in subsequent years of the Cooperation has been to invite consideration of how TMAP (the programme) can better support obligations to other multilateral instruments that may affect the conservation of the ecosystem. The Esbjerg Declaration of 2001 (CWSS 2002) makes a specific reference to considering how TMAP-DH can be optimised *"for future requirements, in particular with regard to the Targets, the EU Habitats Directive and the EU Water Framework Directive"*. The concept is to re-use TMAP data to support inputs to other instruments in such a way that national costs are avoided, or that TMAP could provide parallel functionality both with regard to multilateral as well as trilateral commitments. The value of TMAP would then be increased by the cost offsets.

The recent Oxford Brookes report (Wadden Sea Forum 2003) conducted a thorough review from a legal and management point of view of a range of instruments (with an emphasis on the EC Directives) and how they interact in the region. That study noted a number of organisational and administrative issues that present concerns and barriers to effective interaction. Apart from the EC Directives, the three countries are party to some 70 international agreements with reporting obligations. This paper focuses on the potential use of TMAP data in support of reporting obligations to the Directives, rather than the jurisdictional and policy issues, and does not discuss the other MEAs.

The EC Directives are binding on the nations of the TWSC. The Directives are therefore important policy drivers and of high priority for national response. The Birds and Habitats Directives have been in force for some time and TMAP–DH has already taken cognisance of them. The Water Framework Directive (WFD) is currently in the process of implementation by the EU member states. The growing importance of these to the TWSC is evidenced in recent Trilateral Declarations. It is therefore essential to consider to what extent value-added use can be made of TMAP data to support reporting obligations under these Directives. It is also important to have realistic expectations of the potential influence a regional monitoring programme like TMAP can have on national obligations to the EC. The Wadden Sea conservation area, for all its environmental importance, is only one instance out of many of each nation's suite of concerns and the implementation of the Directives necessarily requires a national perspective. National solutions must be found that suit national policies, processes and institutions that are geographically and contextually remote from the Wadden Sea.

As further context, it should be noted that TMAP-DH is not a "reporting obligation" on the three countries of the TWSC, but is a time-series database of observations designed to support assessments and reporting, i.e. it is not an end product, but an intermediate product (a data archive) that can contribute to a number of end-products.

To briefly summarise the requirements of the three key Directives:

The Birds and Habitats Directives both call for countries to designate a series of protected sites. In establishing the sites, nations submit detailed information on a consolidated form referred to as the Natura 2000 Questionnaire. This approach serves to integrate and harmonise data input for the two types of site. It is not entirely clear what on-going reporting will be required in respect of these Directives. A report every six years is prescribed ("Report on Implementation Measures") which is to include an assessment of the "conservation status" of the specified habitat types and listed species, along with results of "surveillance" (monitoring). While there is an agreed need to clarify and possibly subdivide marine habitat classes, it is clear from the evaluation (CWSS 2004) that TMAP data are a solid base to support such reporting as well as for the generation of indicators and/or assessments of conservation status of habitats and species.

The Water Framework Directive calls for countries to delineate River Basin Districts (RBDs), characterise them, develop River Basin Management Plans and associated monitoring programmes. The management plans are to include "environmental objectives" – the status of which would be assessed through a monitoring programme. There is considerable latitude permitted in implementation, and in interpretation of just what constitutes a management plan or a monitoring programme, and this may vary between RBDs as well. On the other hand the Directive does specify, in its Appendix V, a list of variables that should be measured, and how these might relate to assessment of "status" of a RBD. This list closely parallels the TMAP parameters (CWSS 2004).

Like the Birds and Habitats Directives, the WFD requires the assessment of the "ecological status" and the "chemical status" of the RBDs. These status assessments are to be seen against defined quality elements and relative to "reference conditions".

A common characteristic of these Directives is the reporting (regular but infrequent) on "status" based on assessment and aggregated indicators. To accomplish this, the Directives specify or imply the necessity of a continuous scientific monitoring regime to support the assessments. TMAP is in a good position to support the assessment of the status of sites, species, habitats, and ecosystems under the Birds and Habitats Directives, and is already considerably harmonised with these Directives. To a lesser extent it can contribute to the required assessments of pressures and impacts.

TMAP data is also already closely aligned to the monitoring needs of WFD and likely only needs tuning of TMAP parameters (sample locations, frequency) to be fully compatible. There is a potential important role for TMAP data in establishing "reference conditions" for transitional and coastal waters.

TMAP-Data Handling and the EU Dataflows

European countries are parties to an overlapping network of conventions, treaties, agreements and other instruments, as well as binding EC Directives. Many of these have obligations to report various kinds of data and narrative information at varying frequencies to a range of different authorities. This, coupled with the programmes to assess the state of the European environment and associated "DPSIR" indicators, create an information exchange and delivery process of labyrinthine complexity. The need to reduce this complexity and minimise reporting burdens on countries has been recognised for some time. The response has been a far-reaching programme, coordinated by the EEA, to streamline European "dataflows" – particularly as related to indicators and reporting obligations. The very laudable goal is "*deliver once – report to many*", that is, countries should only have to provide data once and have it distributed to appropriate authorities to satisfy multiple obligations (EEA 2003).

The overarching system, the European Environmental Information System (EEIS), interacts with various international institutions and the EEA to meet reporting obligations, and to provide information for decision-makers and the public (Jensen 2002).

The related Reportnet is defined as a "*suite of IT tools optimized to support the business processes of a data collection network building on a shared information infrastructure*", and comprises a number of components aimed at facilitating information harmonisation and reporting. These include a Reporting Obligations Database (ROD), Data Exchange Modules (DEMs), and a Data Dictionary that link National Repositories and European Data Warehouses to promote harmonisation and consistency in the development of relevant indicators. It is expected that countries will have similar national networks and processes to link national data repositories, and will link institutions through EIONET. The Reportnet concept is shown in Figure 2 below.

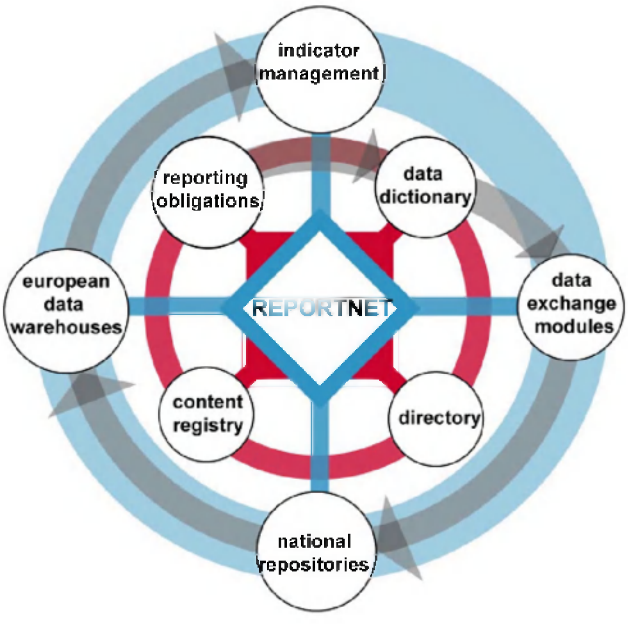

Figure 2. The Reportnet Concept (Diagram courtesy of the EEA).

The result of this approach to streamlining is an EEIS that is itself very complex. Implementation of the concept has advanced unevenly on many fronts and there are a number of issues of technological harmonisation still being addressed.

The EEIS and Reportnet concepts have significant similarities in principle to recommended technology direction of TMAP-DH integration (and possible sharing) of data held in decentralised databases (Saarenmaa et al 2002). Automated extraction of relevant data from National Repositories is proposed using technology and the concept of "mapping" similar to that proposed for TMAP-DH in the TMAP-DH Evaluation (CWSS 2004). On the other hand there are very significant differences in scope and intent. The emphasis of the EEIS and Reportnet process is on meeting reporting obligations to various instruments, rather than assessing the status of targets based on issues of concern. This is a distinct difference from the intent of TMAP and affects the data content and level of aggregation. Many of these reporting obligations require highly aggregated statistics and indicators, as well as narrative assessments of status, provision of legal transpositions (e.g. submissions of laws and regulations), and descriptions of actions and plans. The TMAP database, on the other hand, is a time series of mainly unaggregated science-based observations – designed to be a base for developing indicators and assessments (through aggregation and interpretation) to support reporting, such as the Quality Status Reports and others. The provision of data in a harmonised form to the TMAP-DH is not a "Reporting Obligation" and is not identified in the ROD as such.

There have been initial discussions in the CWSC meetings on the possibility of reducing or eliminating inputs to the TMAP database on the basis that Reportnet and EEIS may serve the purpose. In theory there are potential advantages to taking this approach – that is to extend the "*deliver once – report to many*" concept to deliver data to Reportnet for subsequent use for TWSC assessments. If feasible, it could eliminate the need for TMAP Data Units, and TMAP-DH would be replaced by some service of the EEA Reportnet process, to be used for TWSC assessment activities and production of the QSRs.

Achieving this (at least in the short to medium term) would appear to be problematical in a number of ways that are discussed in the following section.

Concluding discussion

In the short to medium term it does not appear that the Reportnet process would be able to provide the information necessary for the TWSC to assess Targets as they now stand. One of the key principles of the TWSC is to consider the Wadden Sea as a single ecosystem – hence the requirements for harmonised monitoring. These aspects will almost surely be lost if data submission to the Reportnet process (and feed back for TWSC assessments) are limited to those necessary under the EC Directives.

National monitoring systems equivalent to TMAP will continue to be required to support the aggregated assessments delivered to the EEIS, and must be harmonised in order to meet the principle of the TWSC to consider the Wadden Sea as a whole. Therefore replacing the TMAP-DH with services of the Reportnet cannot be done without changes to the principles, and hence the Targets and Common Data Package.

The time-series of scientific monitoring data is essential, and a data handling system with the same (possibly increased) functionality as TMAP-DH will always be required in order to extract, analyse and summarise the data for use in establishing base lines and supporting indicators of "status".

This is not to say that there could not and should not be closer ties and technological integration with the EEIS. One possibility being to establish TMAP-DH as a "European Data Warehouse" with official status as part of Reportnet. This could lead to the consolidation of the TMAP "databases" into a data warehouse (which could be technically distributed).

Whatever the technological evolution, there would still remain a strong need for countries to coordinate their approaches to implementation of the Directives, including for site designation, design of management plans, RBD designation, and monitoring regimes, and for a TMAP Data Handling System that ensures harmonisation and can query, process and analyse the data to serve the objectives of the CWSC.

Put simply, elimination of the time-series of Wadden Sea scientific monitoring observations and the means to analyse them (TMAP-DH) is not an option as it would severely handicap decision-making regarding the Wadden Sea ecosystem.

References

CWSS 1997: TMAP Manual, Trilateral Monitoring and Assessment Program (TMAP), Trilateral Monitoring and Assessment Group, Common Wadden Sea Secretariat, first issued 1997 –continuously updated.

CWSS 2002: Ministerial Declaration of the Ninth Trilateral Governmental Conference on the Protection of the Wadden Sea, ("The Esbjerg Declaration"), Common Wadden Sea Secretariat, Esbjerg, 31 October 2001, pp 104.

CWSS 2004: Evaluation of TMAP Data Handling for the Trilateral Wadden Sea Cooperation, prepared by The Orbis Institute, Ottawa Canada, Common Wadden Sea Secretariat, September, 2004, 60 pp + Annexes.

EEA 2003: Reportnet Brochure, Electronic information tools for streamlining flows of environmental information in Europe, EEA Copenhagen. (also available at www.eionet.eu.int/rn/reportnet2003.pdf).

Jensen S. 2002: Reportnet-EEA EIONET's contribution to a shared European Environmental Information System (available through www.eionet/rn/docu).

Olsen S.B. & Nickerson D. 2003: The Governance of Large Ecosystems at the Regional Scale, Coastal Resources Center, University of Rhode Island, December 2003, 32 pp.

Saarenmaa H., Martin J., Jensen S., Peifer H. and McInnes G. 2002: Development of Common Tools and an Information Infrastructure for the Shared European Environment Information System, EEA Tech Rep 83, Copenhagen, 36 pp.

Wadden Sea Forum 2003: Review of International Legal Instruments, Policies and Management in respect of the Wadden Sea Region – Wadden Sea Forum Report No 1, Oxford Brookes University, August 2003, 93 pp.

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Eutrophication Proxies in the Wadden Sea: Regional Differences and Background Concentrations

J.E.E. van Beusekom

Van Beusekom, J.E.E. 2006: Eutrophication Proxies in the Wadden Sea: Regional Differences and background Concentrations. In: Monitoring and Assessment in the Wadden Sea. Proceedings from the 11. Scientific Wadden Sea Symposium, Esbjerg, Denmark, 4.-8. April, 2005 (Laursen, K. Ed.). NERI Technical Report No. 573, pp. 45-51.

Two Wadden Sea specific eutrophication proxies based on summer and autumn conditions are compared to the more commonly used winter nutrient concentrations. Winter NOx concentrations do not show large regional differences in the Wadden Sea. This contrasts with two Wadden Sea specific Wadden Sea proxies, mean summer chlorophyll and autumn [NH_4 + NO_2]. Both proxies correlate well with riverine Total Nitrogen (TN) input in the Southern Wadden Sea but only summer chlorophyll correlates with riverine TN input. Both proxies correlate significantly, supporting that they both reflect the Wadden Sea eutrophication status. Based on the Wadden Sea specific eutrophication proxies it is concluded that the Southern Wadden Sea has an about two-fold higher eutrophication status than the Northern Wadden Sea. Whereas winter nutrient concentrations may be used to reflect the primary production potential in open sea settings, they do not reflect this potential in areas where eutrophication is driven by advection (import) of organic material.

Key words: Wadden Sea, Phytoplankton, Nutrients, Eutrophication, Eutrophication Proxies, Pre-industrial Conditions

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Introduction

Eutrophication is one of the factors influencing the quality of the Wadden Sea area. Since the earliest nutrient measurements in the Wadden Sea (e.g. Postma 1954, Postma 1966) a clear increase has been documented (e.g. de Jonge & Postma 1974, Hickel 1989, van Beusekom et al. 2001). Among the negative effects associated with the increased nutrient loads are *Phaeocystis*-blooms (Lancelot et al. 1987), a decline in seagrass (de Jonge & de Jong 1992), increased blooms of green macroalgae (Reise & Siebert 1994) and anoxic sediments (Black Spots, de Jong et al. 1999a). One of the challenges in assessing the ecological quality of the Wadden Sea is to develop indicators or proxies that reflect the eutrophication status. After a short description of the present eutrophication status as reported in the newest Quality Status Report 2004 (Marencic et al. 2005), a more detailed elaboration on the use of eutrophication proxies is given.

A trilateral Target was adopted to aim for „A Wadden Sea which can be regarded as an eutrophication non-problem area". A concept for identifying eutrophication problem and non-problem-areas for the Wadden Sea was developed by van Beusekom et al. (2001) in the framework of OSPAR (1997). Regularly, Quality Status Reports document changes in the ecological quality of the Wadden Sea. The Quality Status Report 2004 extends the analyses made for the QSR 1999 (de Jong et al. 1999b) and the results of the above mentioned exercise to develop "Wadden Sea Eutrophication Criteria" (van Beusekom et al. 2001). In this report, recent trends in nutrient loads, nutrient concentrations and in phytoplankton and macroalgae biomass are described. A Target Evaluation and Recommendations are given. The main results can be summarized as follows:

Major conclusions on eutrophication in the QSR 2004

Riverine nutrient input shows a gradual decrease since the mid-1980's. This is reflected by the phosphate concentrations in winter in the Wadden Sea that decreased since the mid 1980's to winter levels of about 1 µM. Salinity normalized nitrate+nitrite concentrations in the German Bight in winter reflect the decreasing TN load, but in the Wadden Sea proper no consistent trend is detectable yet.

The decreasing nutrient input (TN loads by Rhine and Meuse) had a significant effect on the phytoplankton biomass (as chlorophyll) in summer in most of the Southern Wadden Sea. In the Northern Wadden Sea a less clear picture emerges. Only in the Sylt-Rømø-Bight, (decreasing) summer chlorophyll levels correlate with riverine TN input. Toxic blooms are observed in all parts of the Wadden Sea, but no increasing trend or relations with nutrient input are evident. Since the QSR 1999, the most conspicuous blooms were in 1998 and 2000 along the Danish west coast, where large, ichthyotoxic *Chattonella* blooms were observed. The main nuisance blooms were due to *Phaeocystis*. Long term data from the Marsdiep (Western Dutch Wadden Sea) show a decreasing trend in bloom duration. Present macroalgae abundance is below the maximum levels observed during the early 1990's.

The decreasing nutrient input (TN loads by Rhine and Meuse) had a significant effect on the autumn NH_4+NO_2 values in the Southern Wadden Sea. The autumn NH_4+NO_2 values are a good indicator of organic matter turnover in the Southern Wadden Sea (van Beusekom and de Jonge 2002). In the Northern Wadden Sea a less clear picture emerges. In the Sylt-Rømø-Bight an increasing trend of autumn NH_4+NO_2 values was observed suggesting an increased organic matter turnover but a decreasing trend in autumn NO_3 values was observed that correlated with TN input. Data from the other parts of the Northern Wadden Sea did not reveal any trends.

Regional differences

The data analysis highlights regional differences in Wadden Sea eutrophication. In general, the summer phytoplankton biomass and the autumn NH_4+NO_2 values in the Southern Wadden Sea are about two times higher than in the Northern Wadden Sea. This suggests a more intense eutrophication of the Southern Wadden Sea. The reason for this fundamental difference is not yet known, but a possible relation with a more efficient particle accumulation in the southern Wadden Sea has been proposed (van Beusekom et al. 2001). The geographical distribution of phytoplankton biomass reflects the importance of nutrient loads as higher values are observed near the main freshwater sources (Rhine-Meuse-IJsselmeer and Elbe-Weser).

Background values

Compared to background TN concentrations in rivers entering the North Sea of about 45 µM (~0.6 mg/l, Laane 1992) present day mean TN values of 4-5 mg/l are about 7-8 times higher. The present day organic matter turnover rates in the Wadden Sea (as indicated by NH_4+NO_2 values) are about 3-5 times higher than the rates expected with background riverine TN loads. Brockmann et al. (2004) developed background values of TN and Chlorophyll a for the German Bight. They found about 3-5 times higher TN and Chlorophyll levels in the Wadden Sea compared to pristine conditions.

Scope of the present paper

Whereas eutrophication reflects processes like enhanced primary production and remineralisation, most monitoring programmes do not include such process studies. This lack of data becomes especially apparent when trying to reconstruct the historic development of Wadden Sea eutrophication. In such cases proxies have to be developed that reflect the intensity of certain processes. Van Beusekom et al. (2001) suggested that the intensity of the seasonal cycle of NH_4 and NO_2 reflects the intensity of organic matter remineralisation. This concept was applied in the QSR 2004. In addition, a new proxy was developed: the mean summer chlorophyll concentration as an index of pelagic primary production. In this paper, I will discuss the use of both proxies as indicators of Wadden Sea eutrophication. Based on these proxies I will highlight region specific differences in the eutrophication status and suggest region specific background values for these proxies.

Material and Methods

Area description

The Wadden Sea is a shallow coastal sea with extensive tidal flats covering about 50% of the area (Fig. 1). The Wadden Sea region includes an area extending from Den Helder in the Netherlands to the Skallingen peninsula in Denmark, about 500 km of coastline. It is a strip of tidal flats, sandbanks and barrier islands. On average this strip is some 10 km wide, although in some areas it can reach a width of over 30 km. The Wadden Sea area covers approximately 13,000 km^2. Its environment is very dynamic. Wind, tidal forces and water turbulence cause the formation and erosion of the typical landscape elements of the area, the tidal flats, salt marshes, sandbanks and islands. The tidal range is about 1.5 m in the westernmost and northernmost part and increases to about 3 m in the central part near the estuaries of the rivers Elbe and Weser.

Data

The data used in the paper have been described in the QSR 2004. In short: Riverine input data are based on monitoring data that were interpolated to daily loads (Lenhart & Pätsch 2001, updated until 2002). Chlorophyll and nutrient data were derived from the TMAP Data Units. Additional data for the Sylt Rømø Basin are from the AWI time series (van Beusekom, unpublished).

All statistical analyses were made with the statistical package STATISTICA 5.5.

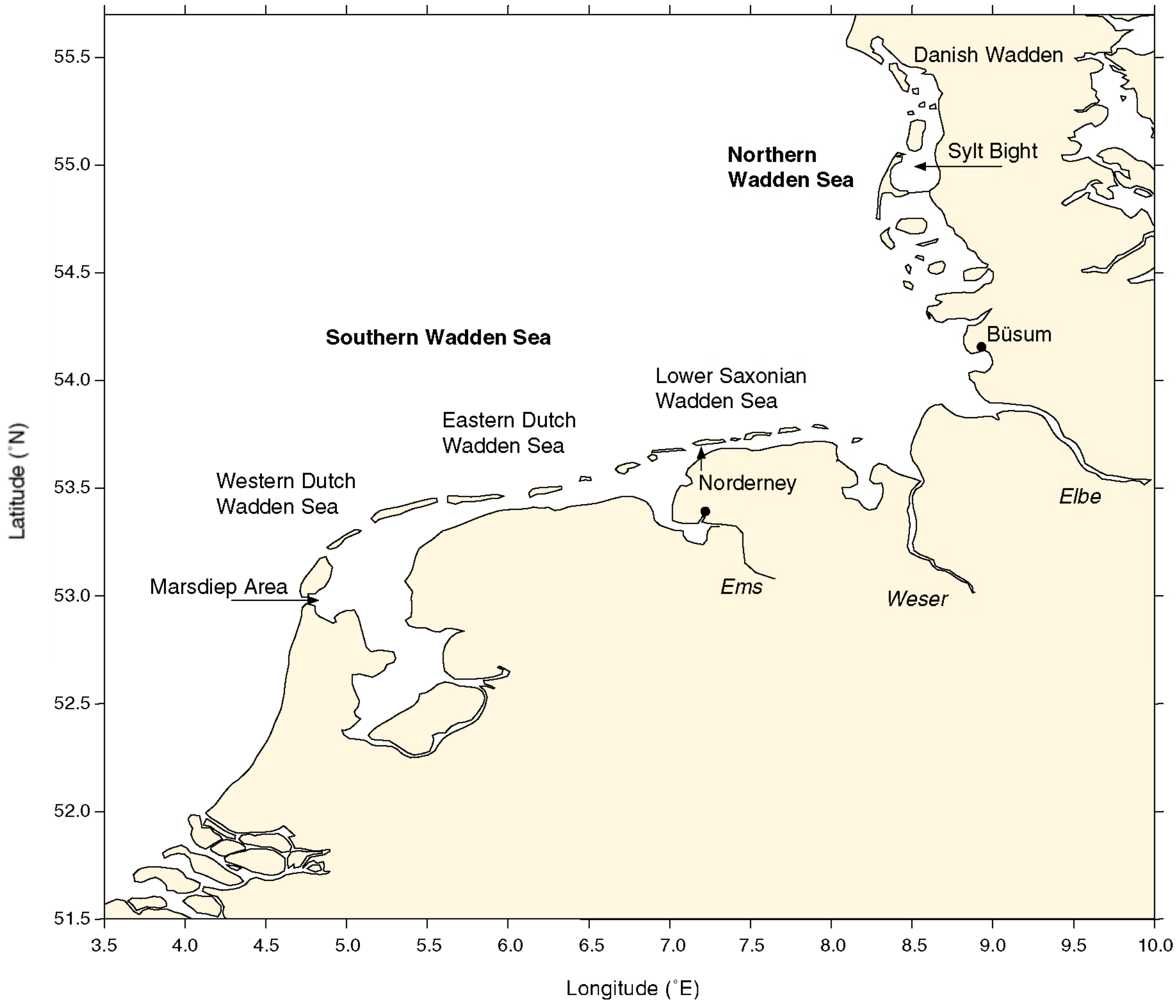

Figure 1. Map of the Wadden Sea with the main subareas used in the data analysis.

Results

Winter Nutrient concentrations as eutrophication indicators?

Winter concentrations generally reflect the amount of nutrients available for phytoplankton growth and are frequently used as an indicator of eutrophication (e.g. Hydes et al. 1999, Ærtebjerg et al. 2003). Also in the QSR 1999 winter nutrient concentrations were evaluated as an indicator of eutrophication status. This exercise was repeated for the QSR 2004 and the general conclusion was that no large interregional differences were observed. Here, some additional data are presented to corroborate this conclusion. Figure 2a presents the mean NOx concentrations as observed during winter (December – March). The concentrations were normalized to a salinity of 27 based on the regression between NOx and salinity. Details of this approach are described by Bakker et al. (1999). The overall mean winter concentrations are 58 µM. The geographical distribution of the normalized concentrations shows highest values near the major fresh water sources (IJsselmeer, Ems,

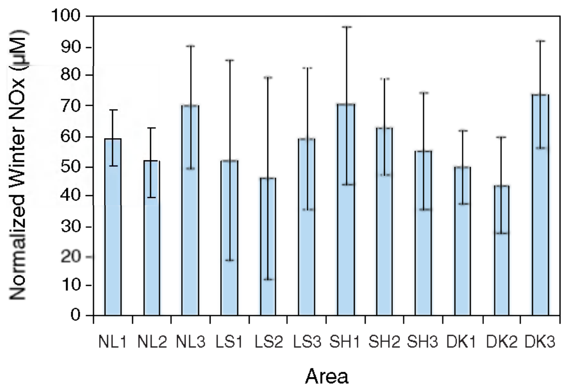

Figure 2a. Mean winter NOx (NO_3 + NO_2) concentrations normalized to a salinity of 27 in the 12 subareas of the Wadden Sea.

Weser, Elbe, Varde AA, Fig. 2b). In general, the concentrations in the Southern part (56 µM) and in the Northern part (59 µM) are comparable. These results suggest that winter NOx concentrations do not resolve any regional differences.

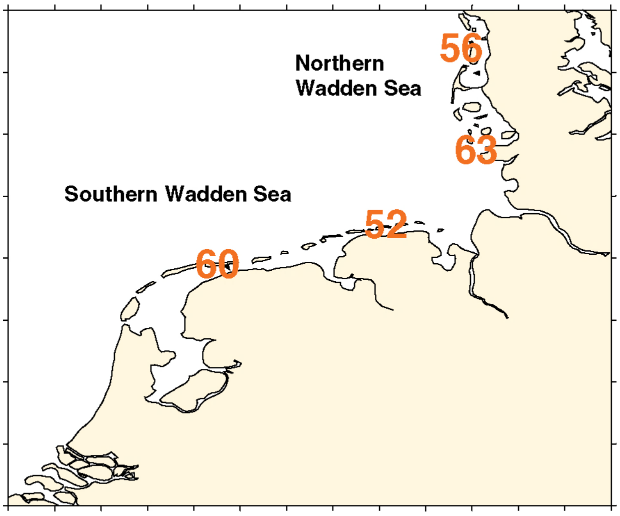

Figure 2b. Mean geographical distribution of winter NOx (µM) for the Dutch Wadden Sea (NL1-3); the Lower Saxony Wadden Sea (LS1-3), the Schleswig-Holstein Wadden Sea (SH1-3) and the Danish Wadden Sea (DK1-3).

New Eutrophication proxies: Autumn NH_4 + NO_2 and Summer Chlorophyll

In the QSR 2004 and in the Wadden Sea Eutrophication Criteria-study two proxies were developed that reflect the eutrophication status of the Wadden Sea: Mean summer chlorophyll concentrations and the autumn NH_4 + NO_2 concentrations. The use of mean summer chlorophyll concentrations was based on the assumption that increased nutrient turnover will support a higher phytoplankton biomass. Mean summer chlorophyll (May – September) gave good correlation with riverine nutrient input in the Western Dutch Wadden Sea, at Norderney (both Southern Wadden Sea) and near Sylt (Northern Wadden Sea). The results are presented in Table 1. The geographical distribution of the mean summer chlorophyll concentrations for each of the time series used in this study shows large spatial differences with values from the Southern Wadden Sea being about two times higher than in the Northern Wadden Sea (Fig. 3).

The mean NH_4 + NO_2 concentrations in autumn (September – November) correlated significantly with riverine Total Nitrogen input (Rhine Meuse) for the Southern Wadden Sea, but not for the Northern Wadden Sea (van Beusekom et al. 2005). The geographical distribution of the mean concentration for each of the time series used shows a similar pattern as for summer chlorophyll with almost two times higher concentrations in the Southern Wadden Sea than in the Northern Wadden Sea.

In the Southern Wadden Sea both eutrophication proxies –summer chlorophyll and autumn NH_4 + NO_2 – show good correlations with riverine Total Nitrogen input. For the Northern Wadden Sea this is less clear: Only for the Sylt time series a significant correlation between summer chlorophyll and

Table 1. Comparison of summer chlorophyll levels (µg/l; May-September) in different parts of the Wadden Sea and their correlation with TN input via Rhine and Meuse. In case of a significant correlation a factor relating riverine input with chlorophyll levels is given. This factor is the slope of the regression multiplied by 10^6 divided by the mean chlorophyll level. The "statistical significance" of the correlation with the Rhine/Meuse time-series is probably related to the size of this river system reflecting both the general precipitation pattern over North Western Europe and Europe-wide changes in the use of fertilizers, implementation of water treatment plants, changes in land use and burning of fossil fuels Data source: TMAP Data Units, DONAR, LANU (J. Goebels), NLOE (M. Hanslik), AWI (van Beusekom), Lenhart & Pätsch (2001).

Area	Period	Mean	Trend/-factor	Correlation
Western Dutch Wadden Sea	1976-2002	18.0	Yes/2.7	r^2 = 0.43 n = 27 p = 0.0002
Eastern Dutch Wadden Sea	1976-2002	19.9	No Trend	
Lower Saxon Wadden Sea (Norderney)	1988-2002	16.6	Yes/2.1	r^2 = 0.308 n = 18 p = 0.008
Southern Schleswig-Holstein	1990-2002	14.2	No Trend*	r^2 = 0.002 n = 13 p = 0.868
Northern Schleswig-Holstein	1990-2002	7.4	No Trend*	r^2=0.12 n = 13 p = 0.245
Sylt-Rømø-Bight	1984-2002	6.3	Yes/2.7 **	r^2 = 0.345 n = 19 p = 0.008
Danish Wadden Sea	1990-2002	8.6	No Trend*	r^2 = 0.18 n = 12 p = 0.15

* Also no trend with Elbe input;
**Also correlated with Elbe input (r^2 = 0.29; p = 0.0158)

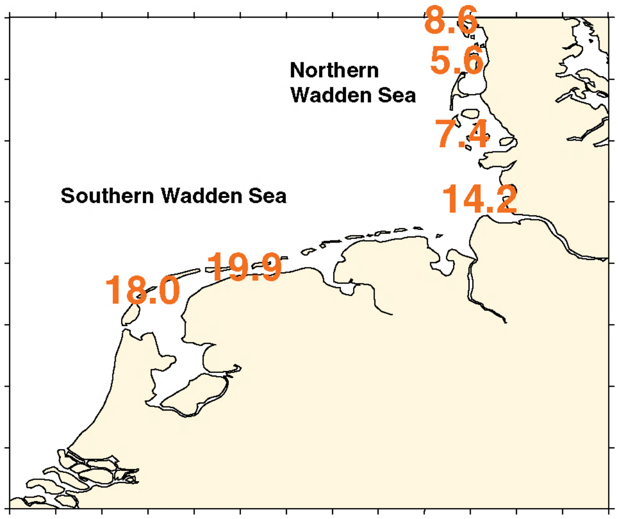

Figure 3. Distribution of the mean values of summer chlorophyll (May-September) in the Wadden Sea. All values are given in µg/l. The period for which the data were averaged is given in Table 1.

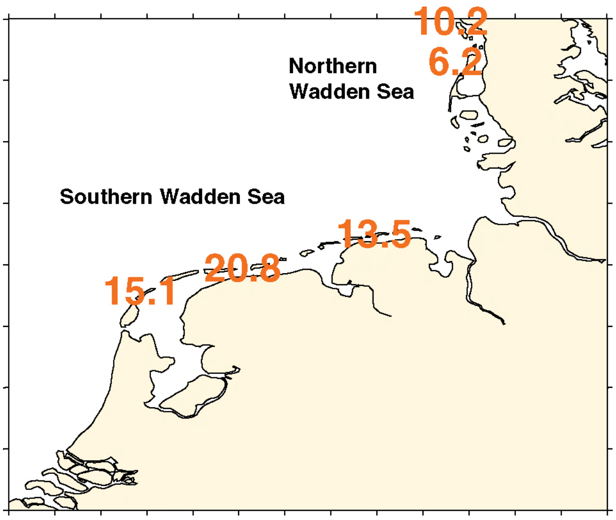

Figure 4. Distribution of mean autumn [NH_4 + NO_2] in the Wadden Sea. All values are in µM. The period for which the data were averaged is given in Table 1.

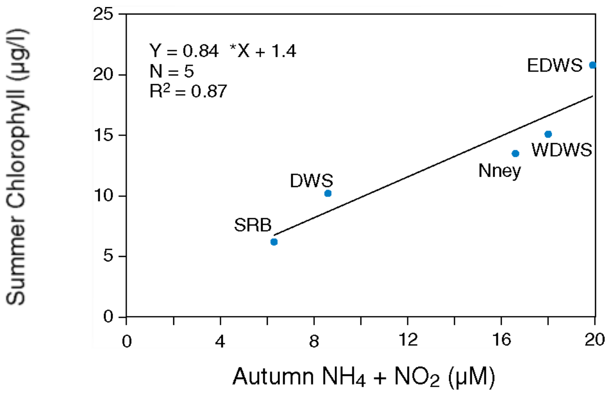

Figure 5. Correlation between the two eutrophication proxies summer chlorophyll and autumn [NH_4 + NO_2)]. SRB: Sylt Rømø Bight, DWS: Danish Wadden Sea, Nney: Norderney, WDWS: Western Dutch Wadden Sea, EDWS: Eastern Dutch Wadden Sea.

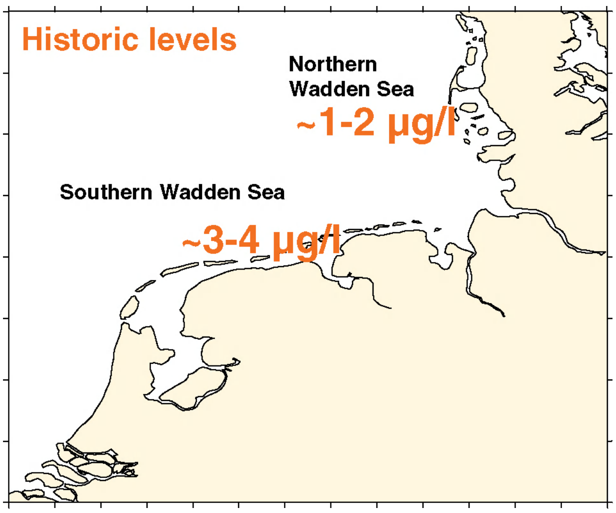

Figure 6. Estimated geographical distribution of historic summer chlorophyll levels (µg/l; May-September) in the Wadden Sea.

riverine Total Nitrogen input was found. Nevertheless, the geographic distribution of the autumn NH_4 + NO_2 (Fig. 4) shows similar spatial trends as found for summer chlorophyll.

If both proxies reflect the eutrophication status properly, they should be correlated. In Figure 5, mean summer chlorophyll is plotted against mean autumn NH_4 + NO_2 for each of the time series where both data are available. The correlation between both proxies is very significant (R^2 = 0.87; p = 0.020; n = 5), and further supports that they reflect the eutrophication status properly.

Regional differences in background values of eutrophication proxies

Although both eutrophication proxies do not show a significant correlation in all Wadden Sea areas, in both the northern and the southern Wadden Sea significant correlations are found with at least one proxy. The excellent correlation between these proxies further supports that both proxies reflect the general eutrophication status. At present the Wadden Sea is about five times more eutrophic than during pre-industrial times (van Beusekom et al. 2001, van Beusekom 2005). As a first estimate of the pre-industrial levels of the eutrophication proxies [autumn NH_4 + NO_2] and summer chlorophyll, a five times lower level can be assumed. Figure 6 and 7 present the geographical distribution of eutrophication proxies under pre-industrial conditions.

Discussion

Winter concentrations are used as a general indicator of the eutrophication status (Hydes et al. 1999, Aertebjerg et al. 2003). The rationale behind this approach is that these concentrations reflect the production potential by primary producers. For the development of Wadden Sea eutrophication criteria (van Beusekom et al. 2001), this proxy was not used because the analysis of carbon budgets suggested that the import of organic matter from the adjacent North Sea was the main driver of Wadden Sea eutrophication (see also van Beusekom et al. 1999, van Beusekom & de Jonge 2002). The present results corroborate this: Whereas winter NOx concentrations do not show any interregional differences between the Southern and the Northern Wadden Sea, the new proxies – Autumn NH_4 + NO_2 and Summer Chlorophyll – do resolve these differences. Both proxies suggest an about two-fold higher eutrophication status of the Southern Wadden Sea as compared to the Northern part. The reason for these differences is not clear yet. Van Beusekom et al. (2001) suggested that in the Southern Wadden Sea particle accumulation is more efficient due to stronger salinity gradients between the Wadden Sea and the open North Sea. This agrees with higher mean annual suspended matter levels in the Dutch Wadden Sea of about 30 mg/l (e.g. de Jonge & de Jong 2002) as compared to 16 mg/l in the Sylt Rømø Basin (1999-2004, van Beusekom unpublished data). A possible explanation for the discrepancy is that due to the better light conditions, the Northern Wadden Sea uses a lower amount of available nutrients more efficiently than the more turbid Southern Wadden Sea.

In this context it is interesting to note that the distribution of sea grass reflects the same geographical pattern as the eutrophication proxies (Reise et al. 2004). It is, however, still unclear to what extent the higher nutrient load or the more turbid conditions contribute to observed regional patterns.

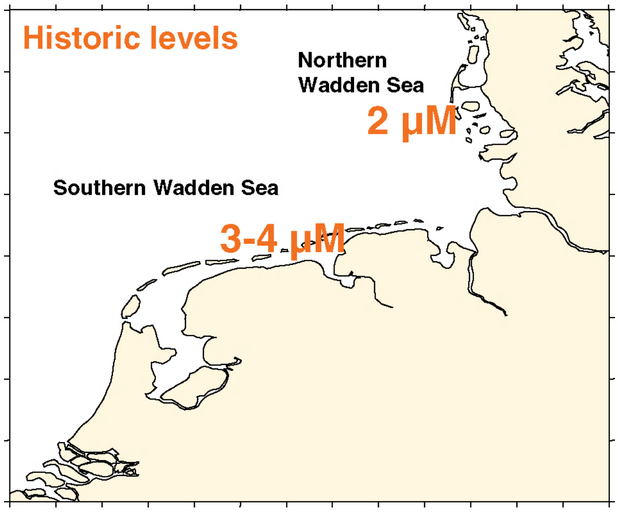

Figure 7. Estimated historic distribution of the autumn [NH_4 + NO_2] levels in the Wadden Sea.

The estimates for background concentrations for autumn NH_4 + NO_2 presented in Figure 7 are in good agreement with previous estimates by van Beusekom et al. (2001), who suggested background values of about 2.5 – 4 µM [NH_4 + NO_2]. A comparison of present levels (last two decades) with the historic estimates suggests a five-fold increase of the present eutrophication status. This does not necessarily imply that production and remineralisation levels were also five fold lower. The comparison of present day production levels between the Southern and Northern Wadden Sea suggested that under less turbid conditions, the available nutrients are used more efficiently. There is evidence to suggest that the historic Wadden Sea was less turbid than the present Wadden Sea (de Jonge & de Jong 1992, 2002, van Beusekom 2005). Taking in account the less turbid historic conditions, van Beusekom (2005) suggested production levels of about 86 gC m-2 a-1 and remineralisation levels of about 108 gC m-2 a-1 for a hypothetical Wadden Sea setting with low direct freshwater input. These values are about three – four-fold lower than present day levels.

Conclusions

Whereas winter nutrient concentrations may be used to reflect the primary production potential in open sea settings, they do not reflect this potential in areas where eutrophication is driven by advection (import) of organic material.

Autumn [NH_4 + NO_2] concentrations and summer chlorophyll levels are good indicators of the eutrophication status of the Wadden Sea.

The Southern Wadden Sea has an about two-fold higher eutrophication status than the Northern Wadden Sea.

The lower nutrient loads in the northern Wadden Sea are partly compensated by better light conditions allowing a more efficient use of the available nutrients.

Pre industrial autumn [NH_4 + NO_2] values are about 3 - 4 µM in the Southern Wadden Sea and ~2 µM in the Northern Wadden Sea, pre industrial summer chlorophyll values are about 3 - 4 µg/l in the Southern Wadden Sea and 1-2 µg/l in the Northern Wadden Sea.

References

Ærtebjerg G., Andersen, J.H. & Hansen, O.S. (eds.) 2003: Nutrients and Eutrophication in Danish Marine Waters. - A challenge for Science and Management. National Environmental Research Institute. 126 pp.

Bakker, J.F., Bartelds, W., Becker, P.H., Bester, K., Dijkhuizen, D., Frederiks, B., Reineking B. 1999: Marine Chemistry. Pp. 85-117 - In: De Jong, F., Bakker, J.F., van Berkel, C.J.M., Dankers, N.M.J.A., Dahl, K., Gätje, C., Marencic, H. & Potel, P. (Eds.); 1999 Wadden Sea Quality Status Report. Wadden Sea Ecosystem No. 9. Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group, Quality Status Report Group. Wilhelmshaven.

Brockmann, U.H., Topçu, D. & Schütt, M. 2004: Bewertung der Eutrophierungssituation (Nährstoffe und Phytoplankton) zur Umsetzung der WRRL in den Übergangs- und Küstengewässern an der Westküste Schleswig-Holsteins (Final Report for LANU, October 2004), Hamburg, 70 pp.

de Jong, F., Kolbe, K. & van Beusekom, J. 1999a: Anoxic Sediment Surface. - In: De Jong, F., Bakker, J.F., van Berkel, C.J.M., Dankers, N.M.J.A., Dahl, K., Gätje, C., Marencic, H. & Potel, P. (Eds.); 1999 Wadden Sea Quality Status Report. Wadden Sea Ecosystem No. 9. Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group, Quality Status Report Group. Wilhelmshaven, pp. 121-123.

de Jong, F., Bakker, J.F., van Berkel, C.J.M., Dankers, N.M.J.A., Dahl, K., Gätje, C., Marencic, H. and Potel, P. (Eds.). 1999b: Wadden Sea Quality Status Report. Wadden Sea Ecosystem No. 9. Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group, Quality Status Report Group. Wilhelmshaven

de Jonge, V.N. & Postma, H. 1974: Phosphorus compounds in the Dutch Wadden Sea. - Netherlands Journal of Sea Research 8: 139-153.

de Jonge, V.N., de Jong, D.J. 1992: Role of tide, light and fisheries in the decline of Zostera marina L. in the Dutch Wadden Sea. - Netherlands Institute of Sea Research Publication Series 20: 161-176.

de Jonge, V.N., de Jong, D.J. 2002: 'Global Change' impact of inter-annual variation in water discharge as a driving factor to dredging and spoil disposal in the river Rhine system and of turbidity in the Wadden Sea. – Estuarine and Coastal Shelf Science 55: 969-991.

Essink, K., Dettmann, C., Farke, H., Laursen, K., Lüerßen, Marencic, H. & Wiersenga, W. (Eds): Wadden Sea Quality Status Report 2004, Common Wadden Sea Secretariat, Wilhelmshaven, 359 pp.

Hickel, W. 1989: Inorganic micronutrients and the eutrophication in the Wadden Sea of Sylt (German Bight, North Sea). - Proceedings of the 21st EMBS. Polish Academy of Science, Gdansk, p. 309-318.

Hydes, D. J., Kelly-Gerreyn, B. A., Le Gall, A. C. & Proctor, R. 1999: The balance of supply of nutrients and demands of biological production and denitrification in a temperate latitude shelf sea - a treatment of the southern North Sea as an extended estuary. - Marine Chemistry 68(1-2): 117-131.

Laane, R.W.P.M. 1992: Background concentrations of natural compounds. - Report DGW-92.033, Den Haag (NL), 84 pp.

Lancelot, C., Billén, G., Sournia, G. A., Weisse, T., Colijn, F., Davies, M.J.W. & Wassman, P. 1987: Phaeocystis blooms and nutrient enrichment in the continental coastal zones of the North Sea. - Ambio 16: 38-46.

Lenhart, H.-J. & Pätsch, J. 2001: Daily nutrient loads of the European continental rivers for the years 1977-1998. - Berichte aus dem Zentrum für Meeres- und Klimaforschung; Reihe B: Ozeanographie, No 40, Hamburg, 146pp.

OSPAR 1997: Common Procedure for the Identification of the Eutrophication Status of the Maritime Area of the Oslo and Paris Commission. - EUT(2) 97/2 Info 1-E: 1-7.

Postma, H. 1954: Hydrography of the Dutch Wadden Sea. - Archives néerlandaises de Zoologie 10: 405-511.

Postma, H. 1966: The cycle of nitrogen in the Wadden Sea and adjacent areas. - Netherlands Journal of Sea Research 3: 186-221.

Reise, K. & Siebert, I. 1994: Mass occurrence of green algae in the German Wadden Sea. - Deutsche Hydrographische Zeitung Supplement 1: 171-188.

Reise, K., van Katwijk, M., de Jong, D., Schanz, A., Jager, Z. 2005: Seagrass. - In: Essink, K., Dettmann, C., Farke, H., Laursen, K., Lüerßen, Marencic, H. & Wiersenga, W. (Eds); Wadden Sea Quality Status Report 2004, Common Wadden Sea Secretariat, Wilhelmshaven, pp. 201-207.

van Beusekom, J.E.E., Brockmann, U. H., Hesse, K.-J., Hickel, W., Poremba, K. & Tillmann, U. 1999: The importance of sediments in the transformation and turnover of nutrients and organic matter in the Wadden Sea and German Bight. - German Journal of Hydrography 51(2/3): 245-266.

van Beusekom, J.E.E., Fock, H., de Jong, F., Diel-Christiansen, S. & Christiansen, B. 2001: Wadden Sea Specific Eutrophication Criteria. - Wadden Sea Ecosystem 14, Wilhelmshaven (Germany), 115 pp.

van Beusekom, J.E.E. & de Jonge, V.N. 2002: Long-term changes in Wadden Sea nutrient cycles: Importance of organic matter import from the North Sea. - Hydrobiologia, 475/476:185-194.

van Beusekom, J.E.E., Bot, P., Göbel, J., Hanslik, M., Lenhart, H.-J., Pätsch, J., Peperzak, L., Petenati, T. & Reise ,K. 2005: Europhication. - In: Essink, K., Dettmann, C., Farke, H., Laursen, K., Lüerßen, Marencic, H. & Wiersenga, W. (Eds); Wadden Sea Quality Status Report 2004, Common Wadden Sea Secretariat, Wilhelmshaven, 141-154.

van Beusekom, J.E.E. 2005: A historic perspective on Wadden Sea Eutrophication. - Helgoland Marine Research. 59: 45-45.

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Assessments of the eutrophication status in the German Wadden Sea, based on background concentrations of nutrients and chlorophyll

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Topcu, D., Brockmann, U. & Claussen, U. 2006: Assessments of the eutrophication status in the German Wadden Sea, based on background concentrations of nutrients and chlorophyll. In: Monitoring and Assessment in the Wadden Sea. Proceedings from the 11. Scientific Wadden Sea Symposium, Esbjerg, Denmark, 4.-8. April 2005 (Laursen, K. Ed.). NERI Technical Report No. 573, pp. 53-71.

Every assessment is based on confident and precise monitoring data which are compared with background data. For deduction of historical background data causal relationships between recent data of eutrophication parameters (nutrients and chlorophyll) and pristine total nitrogen (TN) and total phosphorus (TP) were used. Mixing diagrams allowed the calculation of historical gradients. Modern data have been taken for the period 1997 – 2001. Since the natural variability of these data is high in the German Wadden Sea, mostly caused by hydrodynamic forces, monitoring data of nutrients and chlorophyll were related to mean salinities. Variability has been reduced by elimination of salinity induced fluctuations. By this, the differences between thresholds and recent data, including standard deviations, became more significant. Proposed thresholds, based on natural background concentrations, are used for the classification of Types and Water-bodies in the German Wadden Sea according to the Water Framework Directive. The results for nutrients and chlorophyll are with some exceptions for the North- and (TP good) East Frisian Wadden Sea (phosphate moderate) mostly between poor and bad. Selected long time series for the North Frisian Wadden Sea did not show significant changes. The confidence of the assessments is influenced (i) by the variability, (ii) resolution of sampling in space and time, and (iii) differences between monitoring data and thresholds. Representativity of time series is discussed e.g. for slopes of annual mixing diagrams. Suggestions are given for the improvement of an effective monitoring, considering the assessment confidence. Improvement of assessment and monitoring is an iterative process, which for the monitoring should be supported by specific research, to evaluate the representativity of sampling stations and sampling times and to improve the understanding of causal relationships.

Key words: assessment, natural background conditions, chlorophyll, nutrients, Wadden Sea, Water Framework Directive

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Introduction

Eutrophication processes are still a main issue of coastal pollution. Unbalanced and increased nutrient discharges support the development of harmful and toxic phytoplankton, the accumulation of biomass and the formation of oxygen deficiency. By this the structure and function of coastal ecosystems will be changed significantly (Cloern 2001).

The causative relationships between eutrophication processes in coastal and transitional waters start with elevated nutrient discharges, increasing nutrient concentrations, improving primary production, increasing biomass (Nixon 1995, Cloern 2001, EUC 2005), and reducing the light climate and the depth distribution of macrophytes (Nielsen et al. 2002 a). High biomasses may be accumulated in enclosed bottom layers of stratified areas, causing oxygen depletion during degradation (Dethlefsen & von Westernhagen 1982, 1983, Brockmann & Eberlein 1986).

Especially the Wadden Sea is accumulating organic matter, receiving directly from the passing rivers or by the estuarine type circulation and asymmetric tidal currents importing material from the sea as well. For these reasons the Wadden Sea is *per se* dominated by heterotrophic processes (Postma 1984, Tillmann et al. 2000, van Beusekom et al. 2001).

The increased phytoplankton production may be connected with the formation of harmful/toxic algae at silicate limitation, affecting the whole ecosystem significantly (Zevenboom 1994). A moderate increased biomass production will also cause an increase of macrozoobenthos until oxygen depletion will occur (Pearson & Rosenberg 1978), often coupled with kills of animals and complete changes of the ecosystem (Rachor 1980, 1990, Dyer et al. 1983).

To some degree these relationships can be quantified allowing the calculation of background concentrations from historical TN (total nitrogen.) or TP (total phosphorus): Significant correlations were found between TN and dissolved inorganic nitrogen (DIN), TP and phosphate, TN and chlorophyll (Nielsen et al. 2002 b, Tett et al. 2003, Udy et al. 2005, Brockmann & Topcu 2003), TN and depth minima of macrophytes (Nielsen et al. 2002 a), secchi depth (Nielsen et al. 2002 b, Tett et al. 2003) and chlorophyll and maximum macrozoobenthos biomass (Beukema et al. 2002 , Hargrave & Peer 1973). For this reason the presented assessment, limited to nutrients and chlorophyll, could be extended to other eutrophication parameters, if non linear relationships and interfering processes can be differentiated (s.a. van Beusekom et al. 2001).

Most assessments are based on the comparison between modern data and natural background concentrations. However, natural background data are difficult to achieve in industrialised areas, but especially for nutrients background data have been collected (Meybeck 1982, Laane 1992, Howarth et al. 1996, van Raaphorst et al. 2000, Topcu et al. 2006 in prep.).

For the deduction of historical background data causal relationships between recent eutrophication parameters (nutrients and chlorophyll) and pristine total nitrogen (TN) and total phosphorus (TP) can be used. TN and TP are basic parameters because they include all phases of the nutrient elements N and P, and TN and TP are often given as references for rivers, so that direct links between freshwater and marine areas are possible. Additionally, these values include all primary and secondary effects of eutrophication during the growing season. Therefore, they are seasonally more robust than the inorganic nutrients alone, which often become depleted during the growing season. Only for trend analyses in temperate latitudes inorganic nutrients during winter will be compared for longer time periods, reflecting maximum river discharges during seasonally low biological activity.

Mixing diagrams (nutrients plotted against salinity) allow the calculation of pristine gradients, assuming the same salinity distribution during historical times. These gradients can be compared with recent data, allowing a quantitative, regionally differentiated assessment from the differences.

Recent data have been compiled from 1997 – 2001 only, in order to assess a 5-years period as recommended by OSPAR. No data from research projects have been used, only monitoring data, allowing therefore also an evaluation of the representativity of present monitoring.

Any assessment is based on confident and precise monitoring data which are compared with background data. During the assessment, monitoring aspects like the distances between sampling stations will be evaluated briefly.

For assessments of eutrophication processes, both OSPAR and the Water Framework Directive (WFD) have selected similar parameters. However, significant differences between OSPAR and WFD are the consideration of nutrients which are for OSPAR an important causative factor classified equally to the biological components which are only supporting elements for the WFD during assessing biological elements (ECOSTAT 2004). However, nutrients are the first causative factors within the chain of eutrophication effects. For this reason the nutrients are in the WFD classified in five classes in order to achieve a differentiated classification for all parameters. Another reason is that most of the available eutrophication data are nutrients. Therefore, it is still discussed to give the nutrient conditions for WFD assessments similar weights as the biological elements (COAST 2002). Other differences are the small areas assessed by the WFD in comparison to the OSPAR areas. The differences between the final classes (five for the WFD; two finally for OSPAR), are already under discussion and proposals for an adaptation have been published (EUC 2005). A proposal for the quantitative assessment of nutrients and chlorophyll will be presented here.

Natural variability of modern data is high in the German Wadden Sea, mostly caused by hydrodynamic forces. Therefore, monitoring data of nutrients and chlorophyll were related to mean salinities. Time series of nutrients are normalised for changing salinities by calculation of slopes of annual mixing diagrams. By that, confidence intervals of recent and historical status were reduced and differences became more significant.

The confidence of the assessments is dependent on the (i) differences from background conditions, (ii) steepness of gradients, (iii) residence times, (iv) differences to thresholds, and (v) sampling distances and frequencies. Already simple data inventories can be used for an evaluation of sampling representativity in space and time.

For the final classification according to the five classes of the WFD of nutrients and chlorophyll, compiled scores allow a general impression of the status of the German Wadden Sea concerning key parameters of eutrophication processes. It is suggested to consider insufficient data by decreasing scores.

Material & Methods

Recent data have mainly been compiled by the MUDAB (Marine Umwelt Datenbank) of the DOD (Deutsches Ozeanographisches Datenzentrum, Hamburg). However, many data have also been received from the data originators directly. Data sources are the ARGE Elbe (Arbeitsgemeinschaft Elbe, Hamburg), BFG (Bundesanstalt für Gewässerkunde, Koblenz), BSH (Bundesamt für Seeschifffahrt und Hydrographie, Hamburg), LANU with AlgFes program (Landesamt für Natur und Umwelt, Flintbek/Kiel), NLÖ (Niedersächsisches Landesamt für Ökologie, Norderney) and WGEHH (Wassergütestelle Elbe - Hamburg, Hamburg), IMRN (Institute for Marine Research, Bergen), IFOE (Institute für Fischereiökologie, BFA, Hamburg). For the adjacent areas data have also been involved from national data centres in Denmark and the Netherlands. Generally the quality of data has not been checked.

Background concentrations of nutrients in the German Bight area have been compiled from the literature (Topcu et al. unpublished data). For the rivers, entering or passing the German Wadden Sea natural background data have been estimated by model calculations (Behrendt et al. 2003) (Tab. 1). From this only those of TN (total nitrogen) and TP (total phosphorus) are used without seasonal differentiation. Significant correlations of recent data (1980 – 2001) between recent TN and DIN (dissolved inorganic nitrogen), TP and phosphate were used for the calculation of pristine winter data (November – February) for DIN and phosphate. Significant correlations between recent TN and chlorophyll (1980 – 2001) during the growing season (March – October) were used to estimate historical mean chlorophyll gradients. For this relationship the estuaries were excluded due to the light limitation by high suspended matter especially in the maximum turbidity zones.

The relationship between mean and maximum chlorophyll concentrations of recent data were taken for the calculation of historical maximum chlorophyll data. Since the background concentrations are different for each river, the areas of their mean influences (extension of river plumes) have been estimated roughly from the mean salinity gradients, considering the different amounts of freshwater discharges as well (Fig. 1). The inner German Bight has been divided into squares of about 140 km^2. This allows the calculation of local means and more homogenous analyses and interpretation of data. The mean localities from where the data are originating are indicated by dots within the squares.

The data have been normalized for salinity, using mixing diagrams. For the estuaries and inner coastal waters, including the Wadden Sea, linear regression functions have been used, assuming that mixing is dominating. For the outer coastal waters exponential regression functions have been applied, assuming increasing interferences of different sources towards the marine area. The point of intersection of the fits is at a salinity of about 31.5 (Fig. 2). This means that in the maps beyond this point the exponential relationships are used. For the pristine data similar relations were established, allowing the calculation of historical data for each salinity. Assuming that the mean salinity gradients were at pristine conditions similar as today, historical gradients were calculated, based on mean salinity gradients during all seasons for TN and TP, during winter for DIN and DIP (phosphate), and during the growing season for chlorophyll.

Since the differences between the different thresholds and means of recent data including standard deviations (SD) often are not significant due to overlapping, the variability coupled with fluctuating salinity were excluded. For this reason, the correlations of the regional specific mixing diagrams were used to calculate for every salinity a corresponding value of nutrients or chlorophyll from the linear regressions (mostly) or the exponential regression for the open waters with a salinity > 31.5.

Table 1. Natural background concentrations for nutrients in the German Bight area (all seasons or winter).

Location/Parameter	salinity	TN µM	DIN µM winter	Nitrate *ammonium* µM winter	TP µM	Phosphate µM winter
Eider*	0	29			1.40	
Schleswig-Holstein*	0	37			1.30	
Elbe*	0	39			1.20	
Weser*	0	25			1.00	
Lower Saxonia*	0	25			0.90	
Ems*	0	24			1.50	
Rhein, Lobith*	0	20			1.00	
Wadden Sea	27.5	13			0.77	0.6
Inner Coastal water[1]	30.5	11.5			0.77	
Outer Coastal water (winter) [2]	32	15	15	16 *4*	0.8	0.7
Open Sea [3]	~34.5	10	9	8.5 *0.6*	0.65	0.6

* River data from Behrendt et al. 2003 & pers. comm.

[1] Van Raaphorst et al. 2000, [2] Brockmann & Topcu. 2003, [3] Zevenboom 1994

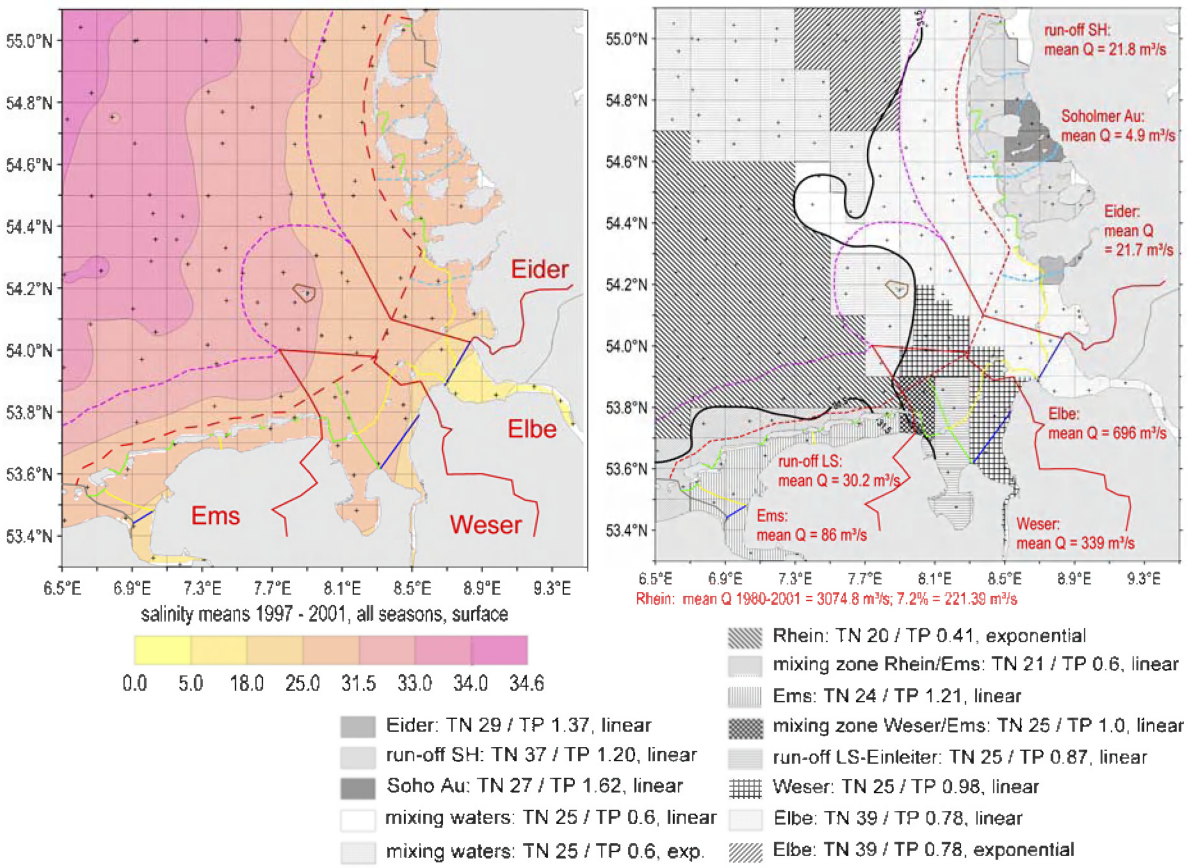

Figure 1. Mean salinity and areas affected by different river plumes.

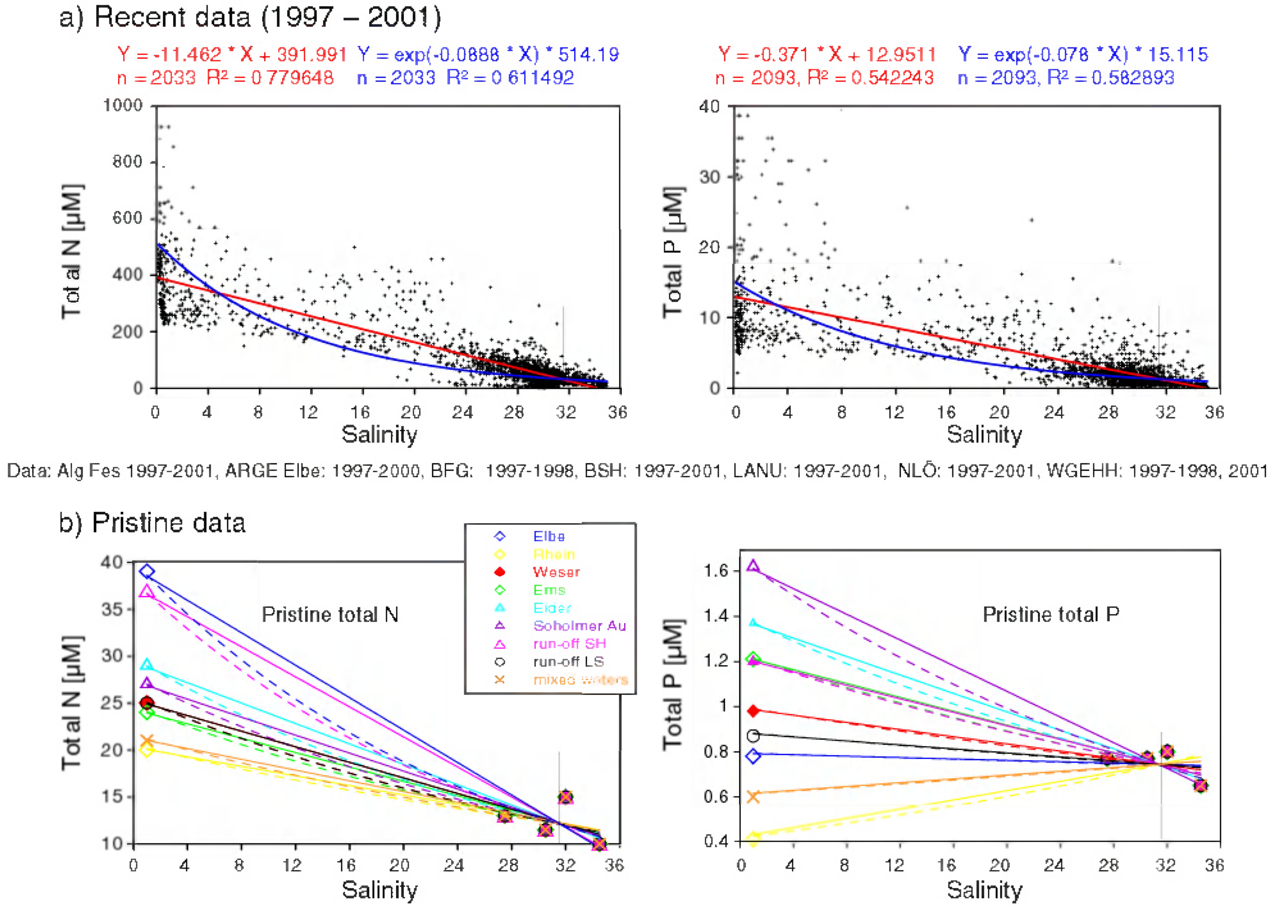

Figure 2. Correlations of TN and TP with salinity, recent (1997-2001) and pristine data.

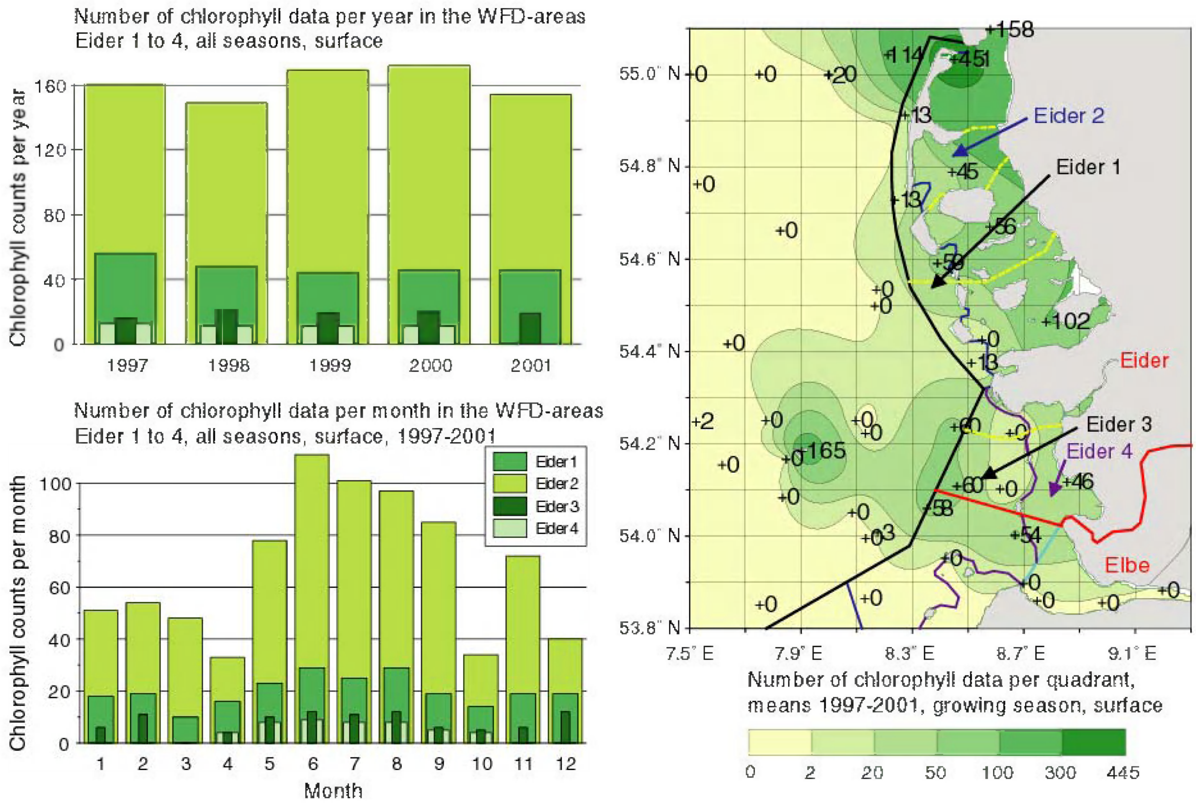

Figure 3. Inventory of chlorophyll data during1997 – 2001.

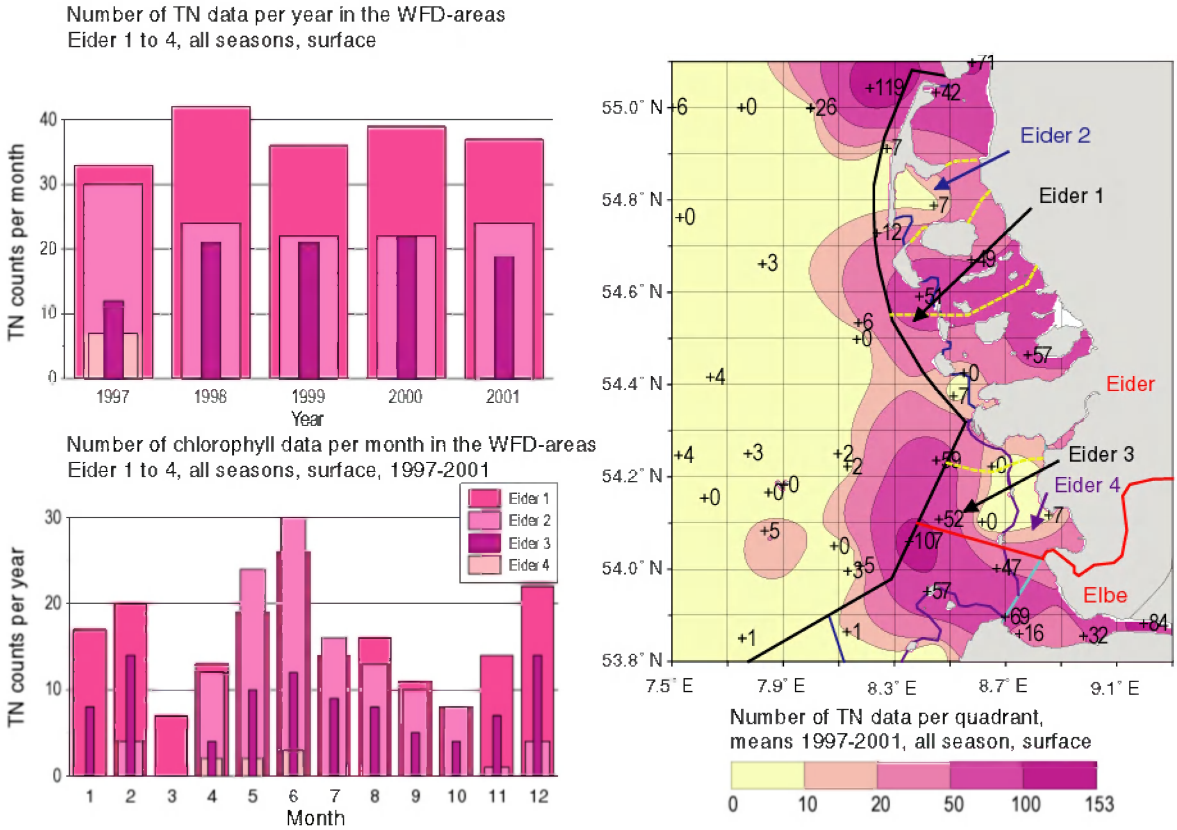

Figure 4. Inventory of TN data during1997 – 2001.

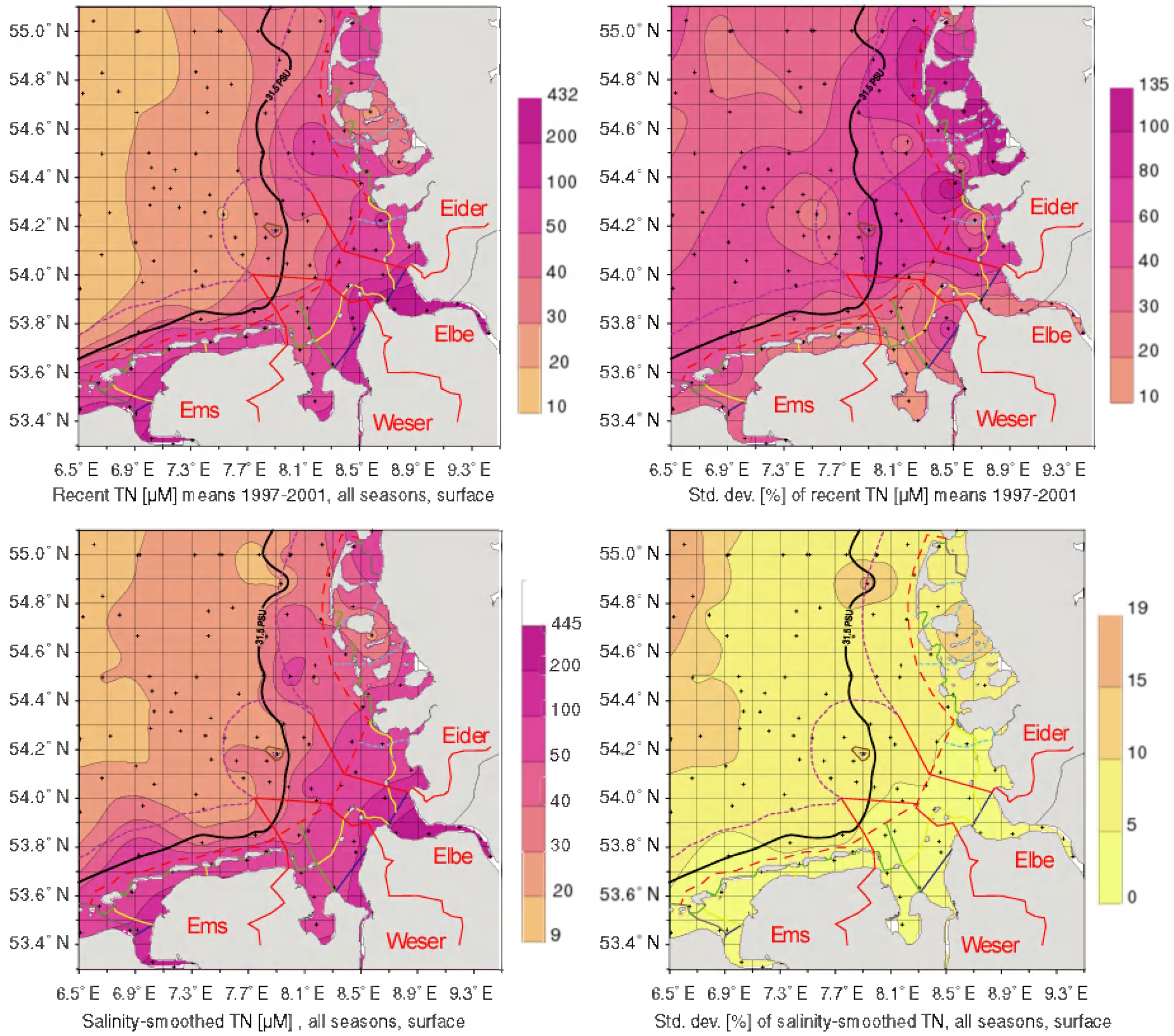

Figure 5. Mean gradients of TN during1997 – 2001 (all seasons), and salinity-smoothed data with standard deviations.

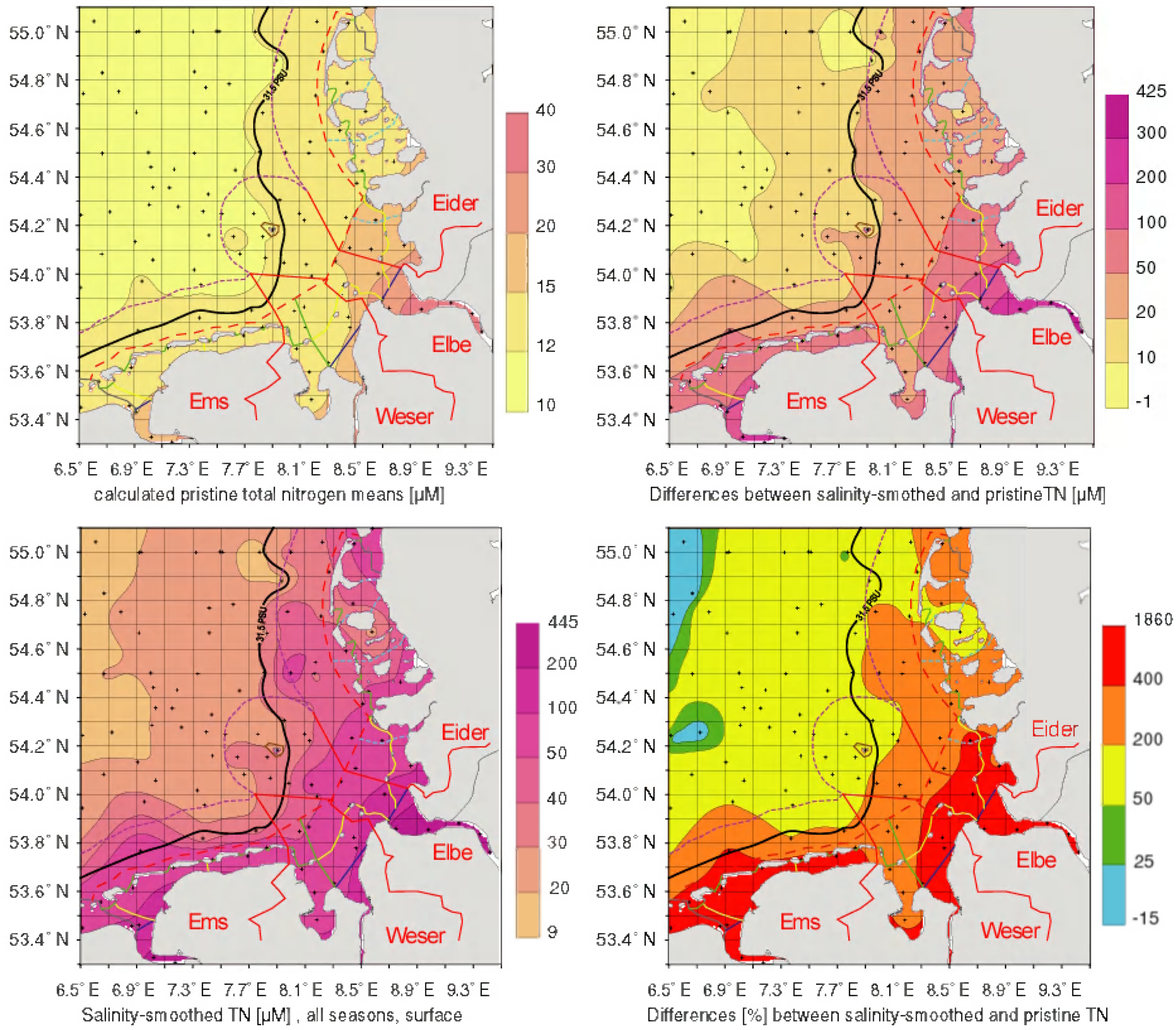

Figure 6. Natural background concentrations, salinity-smoothed recent data and differences for TN.

These data are used as "salinity smoothed" data for the assessment. The correlated data were combined stepwise for each full salinity unit (1 PSU-step, PSU = practical salinity unit), for which means and SD were calculated. These "salinity smoothed" data were inserted into the boxes according to their original positions.

DIN and phosphate (DIP) were calculated for the winter period (November – February) only, representing maximum concentrations. Chlorophyll was mainly analysed for the growing season (March – October).

Differences between background concentrations and recent data were calculated as absolute concentrations and additionally as % of deviations from background values. These calculations allow a comparison of deviations from background data for different parameters and can be used for a classification as well.

Maps and time series have been plotted, using SURFER 7 (Golden Software), x/y diagrams with GRAPHER (Golden Software).

Results

Processing of data

As examples of the available data for the period 1997 – 2001 inventories for TN and chlorophyll are presented for the North Frisian Wadden Sea (Fig. 3 and 4). The data originate mostly from locations of research institutions (Helgoland and List/Sylt) whereas some areas, indicated as individual Waterbodies, are only scarcely sampled. Most data are originating from the Type "Eider 2" which includes the frequently measured station at List. The number of available data was similar during the different years, as well as for the main part of the growing season (May – September).

For TN, as an example for nutrients, the inventory shows in the coastal water of Schleswig-Holstein a similar distribution of data density as for chlorophyll (Fig. 4). However, the number of data was reduced and the monthly distribution was more fluctuating. Along the Wadden Sea of Lower Saxonia mostly only 10 data for each square were available for the period 1997 – 2001.

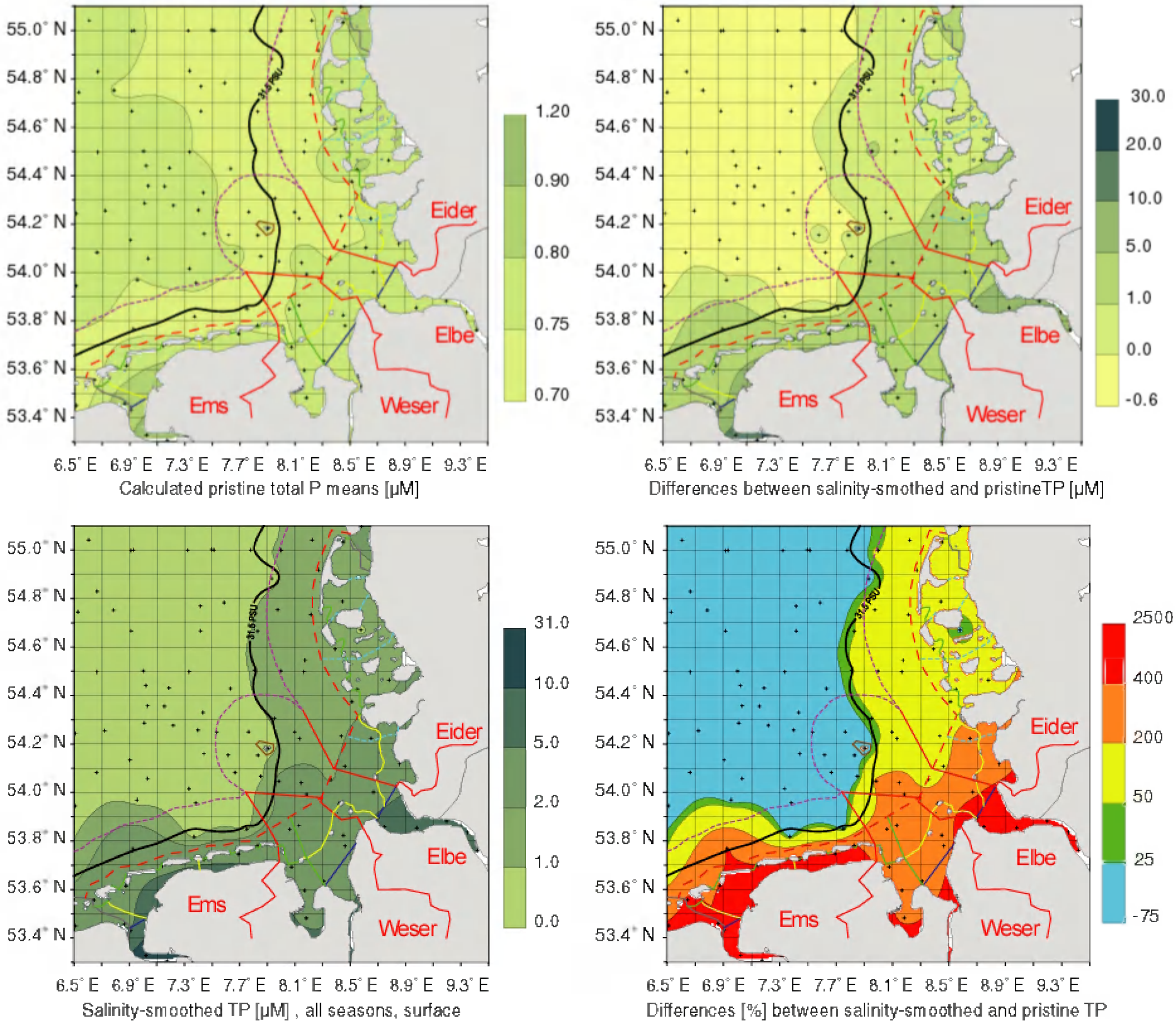

Figure 7. Natural background concentrations, salinity-smoothed recent data and differences for TP.

In order to exclude the hydrodynamic variability, coupled with changing salinity, the data within the different boxes of about 140 km² had been transformed in relation to the mean salinity. For comparison as an example TN is shown (Fig. 5). The gradients of TN remained nearly unchanged after transformation with 20 – 30 µM at salinities > 31.5 and increasing concentrations, partly of more than 60 µM in the Wadden Sea. However, the standard deviations were reduced from 40 – 100% to mostly less than 10%.

Comparison of pristine and recent data

The recent (1997 – 2001), salinity smoothed data have been compared with the background data estimated for the same salinity. The calculated pristine TN concentrations were mainly around 13 µM in the Wadden Sea and increased within the estuaries to more than 20 µM (Fig. 6). The salinity smoothed recent (1997-2001) data, reached 30 – 100 µM in the tidal flats and more than 300 µM in the estuaries. The differences were mostly between 20 - 70 µM. In relation to the background concentrations between 100 and 400% were surpassed. Along the coast of Lower Saxonia and around the Elbe mouth recent TN concentrations were more than 400% above background data.

Pristine TP were in the Wadden Sea between 0.75 - 0.8 µM (Fig. 7). Recent TP concentrations surpassed 1 – 5 µM, resulting in differences of 0.1 – 4 µM, or less than 50 to more than 400% of background concentrations.

In the Wadden Sea concentrations of DIN were calculated as 9 – 11 µM (Fig. 8). Recent concentrations in this area were about 40 µM and up to 100 µM near the Elbe mouth. The differences were correspondingly 30 – 90 µM or 300 – 500% of background values.

Historical phosphate data were in the Wadden Sea during winter calculated to around 0.5 µM (Fig. 9). Recent mean data surpassed 1.6 µM along the coast of Schleswig-Holstein and 1.1 µM along the coast of Lower Saxonia between 1997 – 2001. The corresponding differences were 1.1 or 0.6 µM, or between 100 and more than 200% of pristine data.

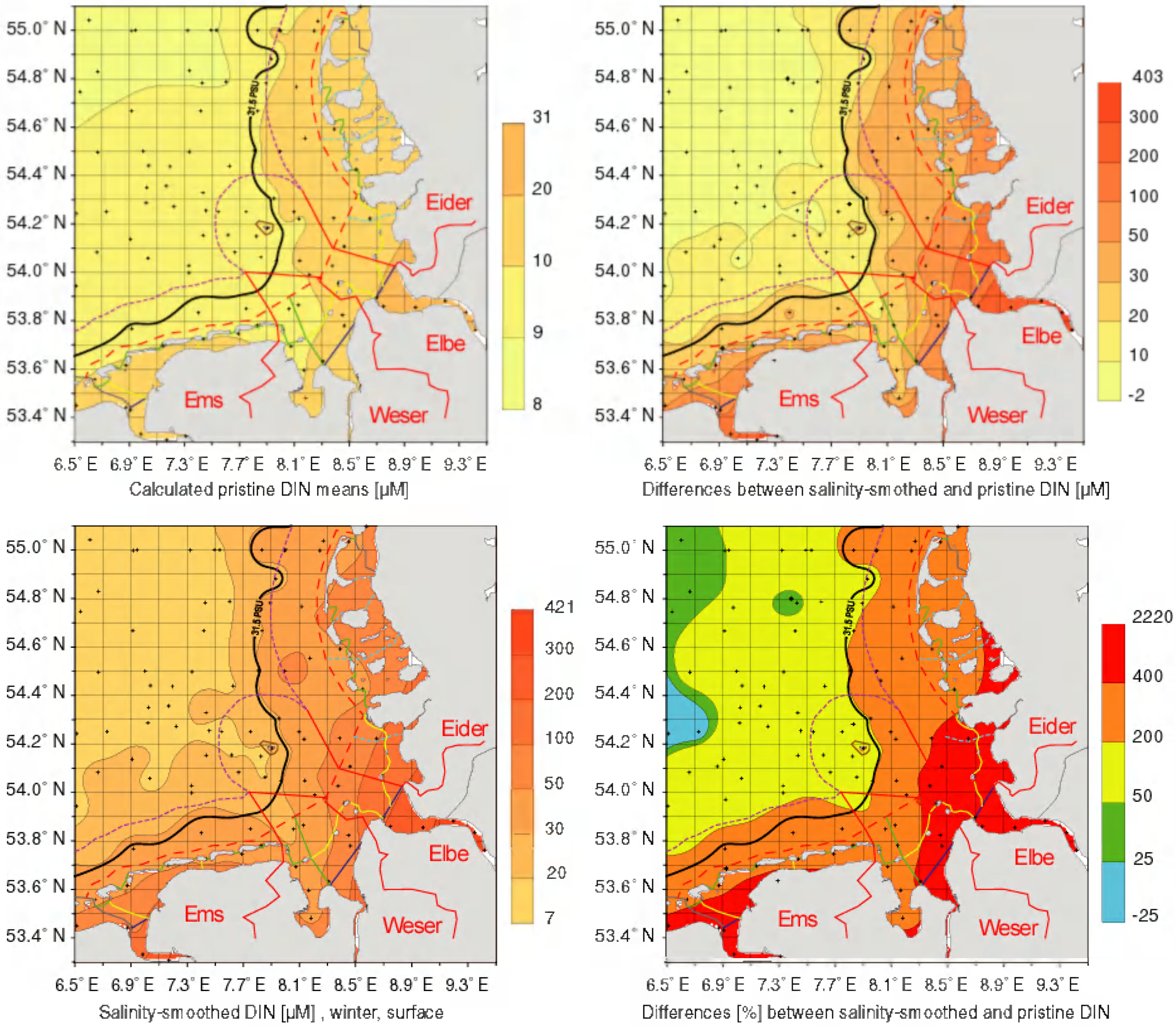

Figure 8. Natural background concentrations, salinity-smoothed recent data and differences for DIN.

The calculated natural mean background concentrations of chlorophyll were in the Wadden Sea during the growing season between 2 - 2.5 µg/L (Fig. 10). Modern mean chlorophyll concentrations were mostly in the range between 7 and 10 µg/L. However, the standard deviation of the original, not "salinity smoothed data were mostly above 50%, often in the range of 80%. For the salinity smoothed data SD was < 10% mostly. The differences between recent and pristine mean chlorophyll were in the tidal flats in the range of 4 – 7 µg/L or between 100 and 300% of background data. Near the Elbe mouth 400% were surpassed.

In the Wadden Sea as background concentrations of maximum chlorophyll about 11 µg/L were estimated. For recent data mostly 20 – 80 µg/L were detected (Fig. 11). The differences were correspondingly 12 – 50 µg/L or between 100 and 400%. Exceptionally low differences were detected in front of the Jade and Ems. There the differences were below 50%, or 5 µg/L, caused by recent maxima below 15 µg/L.

Assessment consistency

As an example for the consistency of data during a longer time period, chlorophyll means and maxima measured in the North Frisian Wadden Sea (Type Eider 1 & 2) are compared with the number of measurements/month/year (Fig. 12). For this area a consistent time series is available between 1987 and 2001.

For 1987 - 2001 the most frequent sampling was performed between May and September. Objective of the AlgFes-programme of LANU was to detect nuisance or toxic phytoplankton species. However, during March already chlorophyll increased and maxima of more than 90 µg/L were detected. The minima of means during winter dropped to less than 3 µg/L, but maxima remained mostly above 5 µg/L.

Time series of TN and TP for all seasons and mean chlorophyll concentrations during the growing season were normalised to changing salinities by calculation of slopes of annual mixing diagrams for the Types "Eider 1 and 2" (Fig. 13). For some years there were no significant correlations, due to

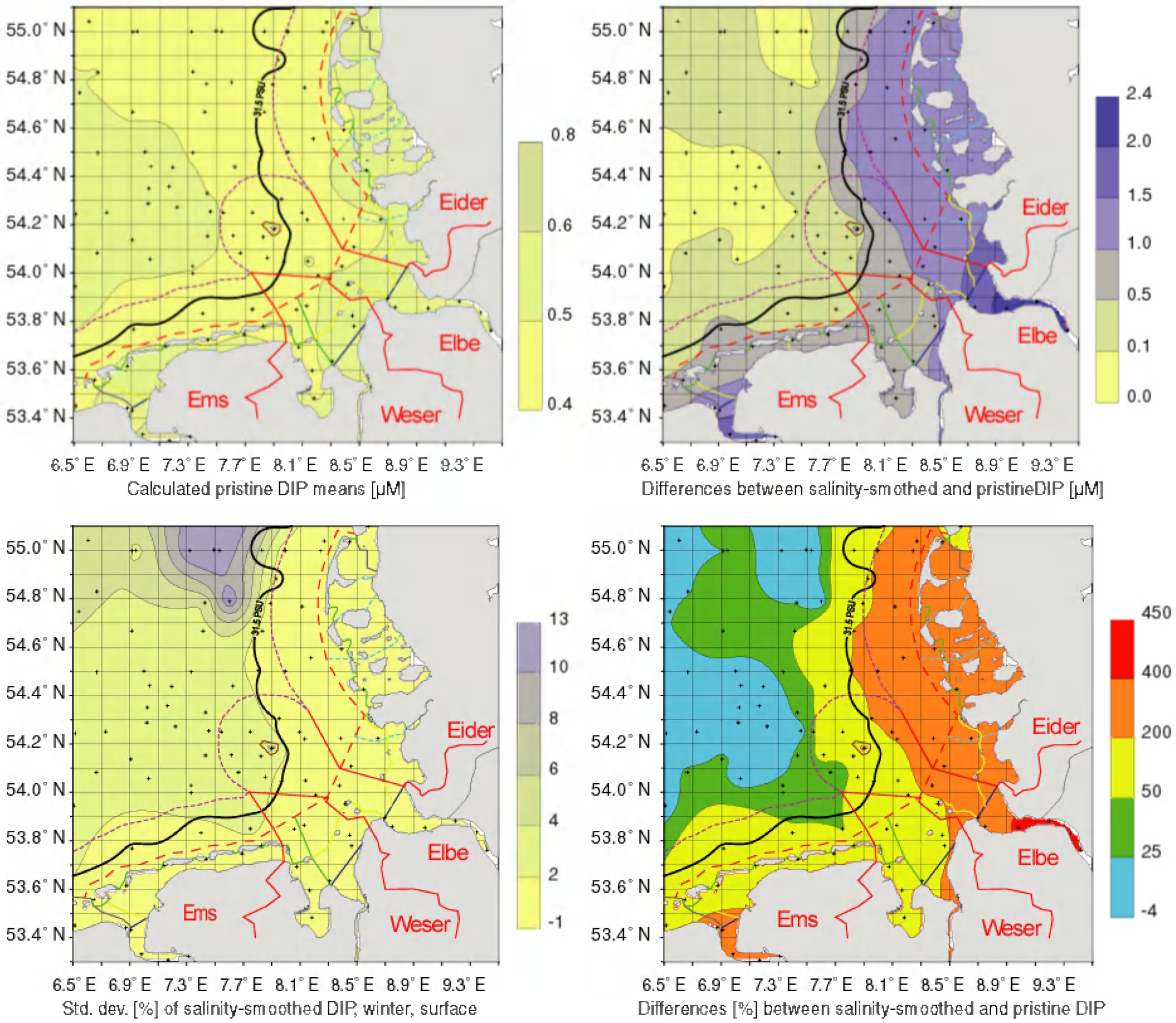

Figure 9. Natural background concentrations, salinity-smoothed recent data and differences for DIP.

the lack of data mostly. Non significant or inverted mixing diagrams have been excluded. The slopes for TN were in the range of -10 to -20 mostly, those of TP around -0.4 and mean chlorophyll showed a high variability around -3. All slopes remained above those of natural background data, deduced from historical mixing diagrams (Fig. 2). There are no significant trends, neither for chlorophyll nor for the nutrients.

Comparing of scoring according to the WFD and COMPP

To enable a comparison between the scoring by WFD and COMPP (Comprehensive Procedure) by OSPAR (EUC 2005) a classification schema was proposed for the WFD, including an adaptation between the present three classes in OSPAR and the five classes in the WFD (Fig. 14). The classes high and good correspond to the final Non Problem Area (NPA) of OSPAR and the classes moderate, poor and bad to the final OSPAR Problem Area (PA). Transitionally a Potential Problem Area (PPA) is used by OSPAR for areas where elevated nutrient concentrations but no effects are observed or where the assessment remains unclear.

The threshold for good/moderate was laid at a level corresponding to the "elevated" concentrations as defined by OSPAR as 50% above natural background concentrations (EUC 2005). The range below 50% above natural background conditions was divided at 25% into high and good, the range above 50% was divided at 200% and 400% into moderate, poor and bad.

The rough differentiation of the classes moderate – bad was proposed at 200 and 400% above natural background data according to the ranges of recent data to achieve similar numbers of data for each of the classes. The colours selected for Fig. 6-11 have been chosen in a way that they illustrate the differences (%) between recent and pristine data.

The differences have been compiled as a first classification, using the colours, proposed by the WFD (Fig. 15). The different scores for nutrients (TN & DIN, TP & DIP) and chlorophyll (means & maxima) have been compiled for N, P and chlorophyll (Fig. 15). The Types are indicated by numbers for the catchment areas. In the coastal waters, nitrogen concentrations were classified as poor, phosphorus

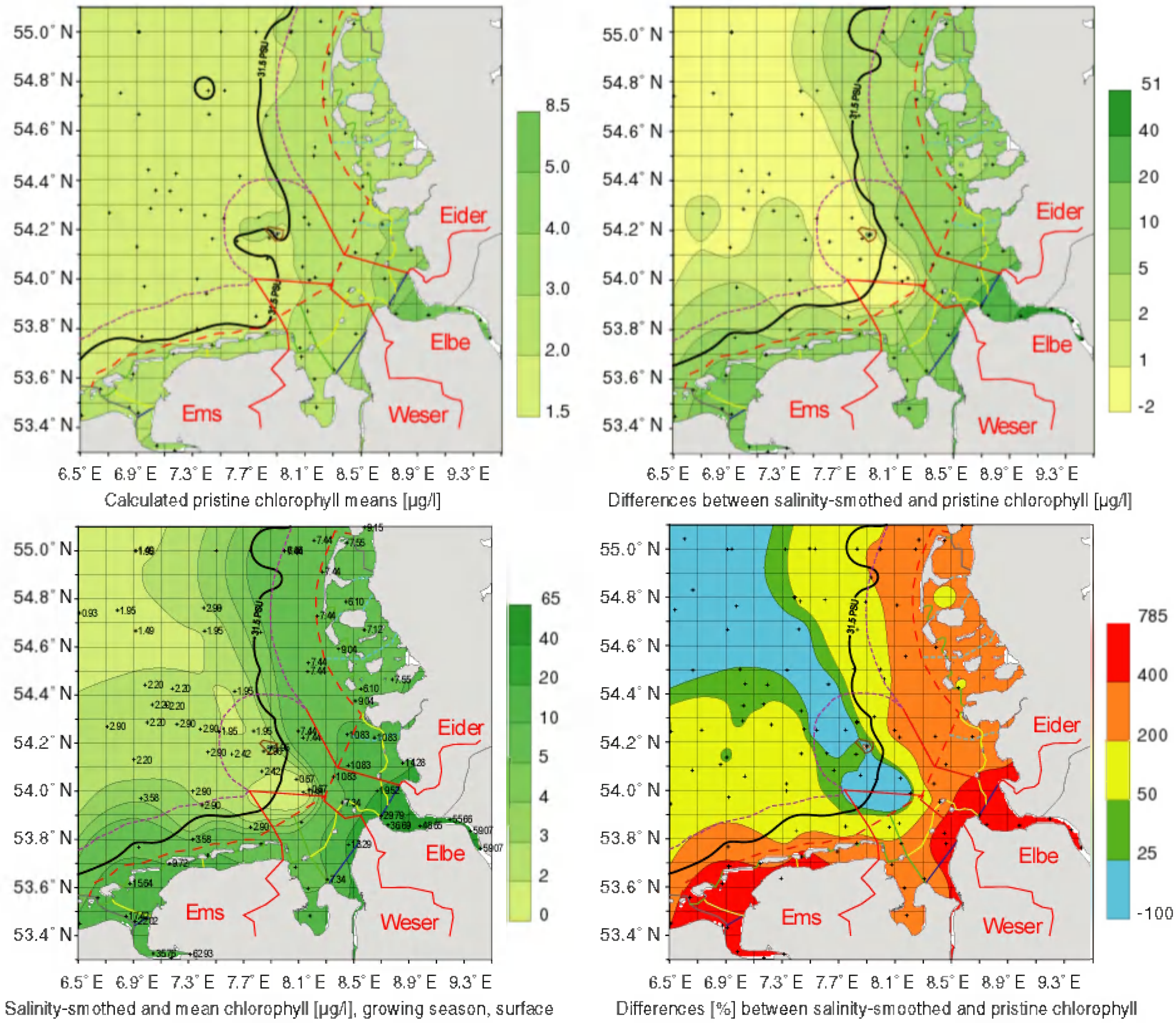

Figure 10. Natural background concentrations, salinity-smoothed recent data and differences for mean chlorophyll.

as moderate, and chlorophyll as good. For the Wadden Sea the nitrogen status was mostly poor, near and within the estuaries even bad. The phosphorus status was mostly classified as poor, of which phosphate was classified as moderate along the East Frisian Wadden Sea. In this area mean chlorophyll was scored as moderate and maximum chlorophyll often as good or high. Lack of data is indicated by white columns.

A 3D-plot for the North Frisian coast shows from the shore towards offshore (north – west) the deviation of the mean salinity-smoothed concentrations of TN from the natural background concentrations and the different thresholds (Fig. 16). The mean concentrations and the residual standard deviations have been plotted as three narrow layers. The variability of background concentrations and thresholds, which is mostly below 10%, has been neglected.

The TN concentrations are mainly between the thresholds moderate/poor and poor/bad. This means that most of the area was classified as poor (Fig. 6). South of the peninsula Eiderstedt TN was surpassing 400% of background concentrations, classifying the area as bad. Around the island of Föhr differences between recent and natural background concentrations were below 200% of background data. This area was classified as moderate. By this 3D-plot the differences between monitored recent data and threshold become more visible which is important for the estimation of classification precision.

Discussion

Natural background conditions

Natural background conditions are needed as references for the assessments in the WFD as well as the Comprehensive Procedure by OSPAR. Background concentrations for nutrients and chlorophyll have been deduced from historical and modelled TN and TP data for the German Wadden Sea (Brockmann & Topcu 2003). Causal relationships, reflected by significant correlations between recent data sets in different areas (Nielsen et al. 2002 b, Tett et al. 2003, Udy et al. 2005) are assumed that they have been

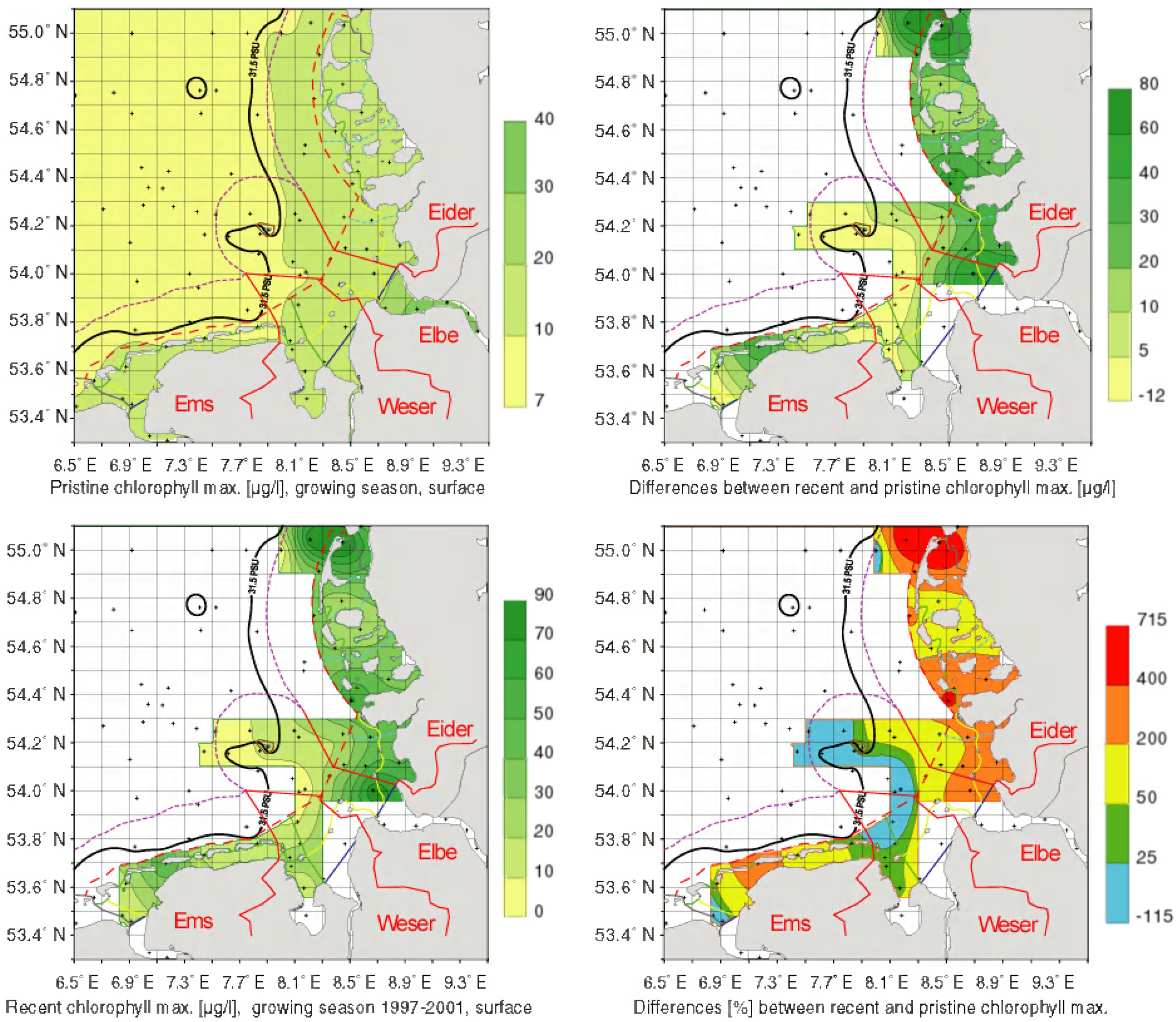

Figure 11. Natural background concentrations, salinity-smoothed recent data and differences for maximum chlorophyll.

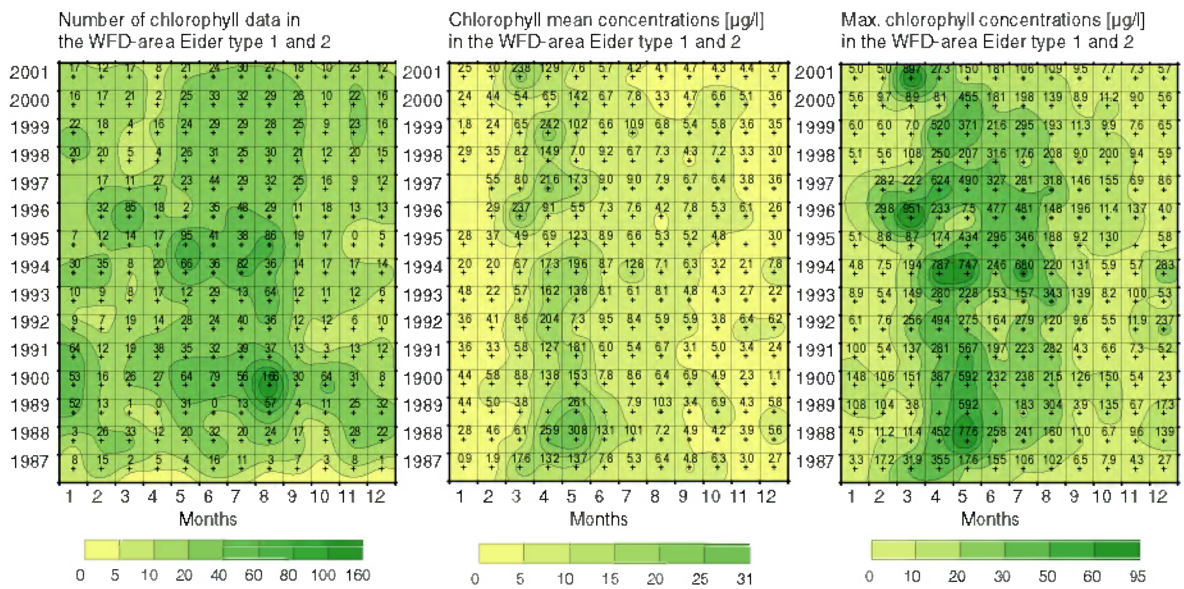

Figure 12. Time series of chlorophyll (1987- 2001) for Eider-Types 1 and 2.

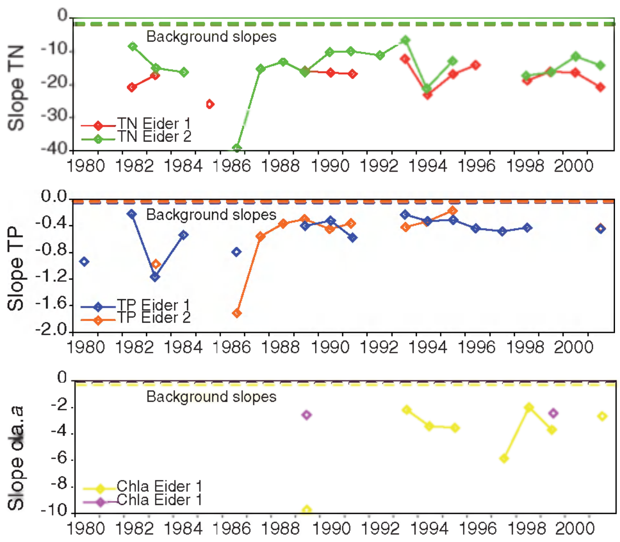

Figure 13. Slopes of mixing diagrams of mean chlorophyll, TN and TP for Eider-Types 1 and 2.

		Ecological Quality Objective Eutro				
OSPAR COMPP	Initial assessment	Non-problem area	Potential problem area		Problem area	
	Further assessment	Non-problem area		Problem area		
WFD	Class	High	Good	Moderate	Poor	Bad
	Numeral for evaluation	1	2	3	4	5
	WFD-Value	>0.8	0.7-0.8	0.5-0.7	0.25-0.5	<0.25
Proposal	% deviation from background	<25	25-50	50-200	200-400	>400

Figure 14. Proposed classification scheme.

valid also during historical conditions. For this reason they were used for the deduction of background concentrations also for parameters for which no or only few estimates of historical conditions have been published. For the ratios between TN and DIN it must be assumed that the historical contribution of DIN to TN was much lower because mainly dissolved organic nitrogen is discharged by rivers in remote areas (Hedin et al. 1995) opposite to the dominance of DIN for high recent nitrogen discharges (Howarth et al. 1996) For the Elbe the contribution to TN is 65% for nitrate and 80% for DIN (Pätsch & Lenhart 2004). However, at least rough estimates can be performed until better historical data are available.

It is very difficult to collect pristine data for anthropogenic modified areas like the Wadden Sea, located within the eutrophicated coastal water. Van Raaphorst et al (2000) calculated natural background values from early seasonal measurements during the 1930s. However, it must be assumed that at that time population density in the catchment areas was so high, that nutrient discharges were already anthropogenically affected (Howarth et al. 1996). For this reason the compiled natural background concentrations of nutrients have been compared with several data from independent estimates in remote areas of temperate latitudes (Brockmann & Topcu 2003) for which mostly lower concentrations have been reported. From this it can be assumed that the chosen values are at least not too high. Additionally, the modelled background data for German rivers (Behrendt et al. 2003) are consistent with area specific freshwater inputs. Therefore it can be assumed that the proposed values are reasonable.

The natural background concentrations in the Wadden Sea are involved within the mixing processes between rivers and the open sea. Estimates by van Raaphorst et al. (2000) for the Wadden Sea and the inner coastal water at the Dutch coast were transferred to the German Bight (Tab. 1, Fig. 2) allowing to establish nearly consistent gradients. Only the data for the outer coastal water, combined from different references are to a small degree too high within the mixing lines and therefore inconsistent. However, these are winter values only, reflecting a minimum biological activity.

Since TN (and TP) include all nitrogen (phosphorus) components within the water column it can be used for assessments of all seasons as a first estimate. A seasonal differentiation of the assessment e.g. of inorganic nutrients during the growing season requires much more data due to the fast turnover which are mostly not available. For inorganic nutrients it is therefore difficult to establish direct quantitative relationships between different causal connections of eutrophication processes, but they are used in ecosystem models and for indications of specific relations (van Beusekom et al. 2001). In shallow areas like the Wadden Sea the sediment plays an important role as a seasonal sink of nutrients where up to 50% of deposited organic matter may be remineralised (van Beusekom et al. 1999, Heip et al. 1995). These interactions are neglected here due to the lack of historical data.

Additionally, dissolved organic compounds are often not analysed and not considered in models, but seasonally they are the dominating compounds (Brockmann et al. 1999a). Also for the particulate matter which is imported to the Wadden Sea it seems to be impossible to establish natural background concentrations due to interfering processes. Already due to the often steep vertical gradients of suspended matter, sufficient sampling along the water column is difficult, also in the tidal channels as has been shown during the TRANSWATT-investigations (Dick et al. 1999).

On the other hand, TN and TP values include all primary and secondary eutrophication effected components during the growing season and are key parameters because of many causal relationships (e.g. Beukema et al. 2002, Nielsen et al. 2002 a, b

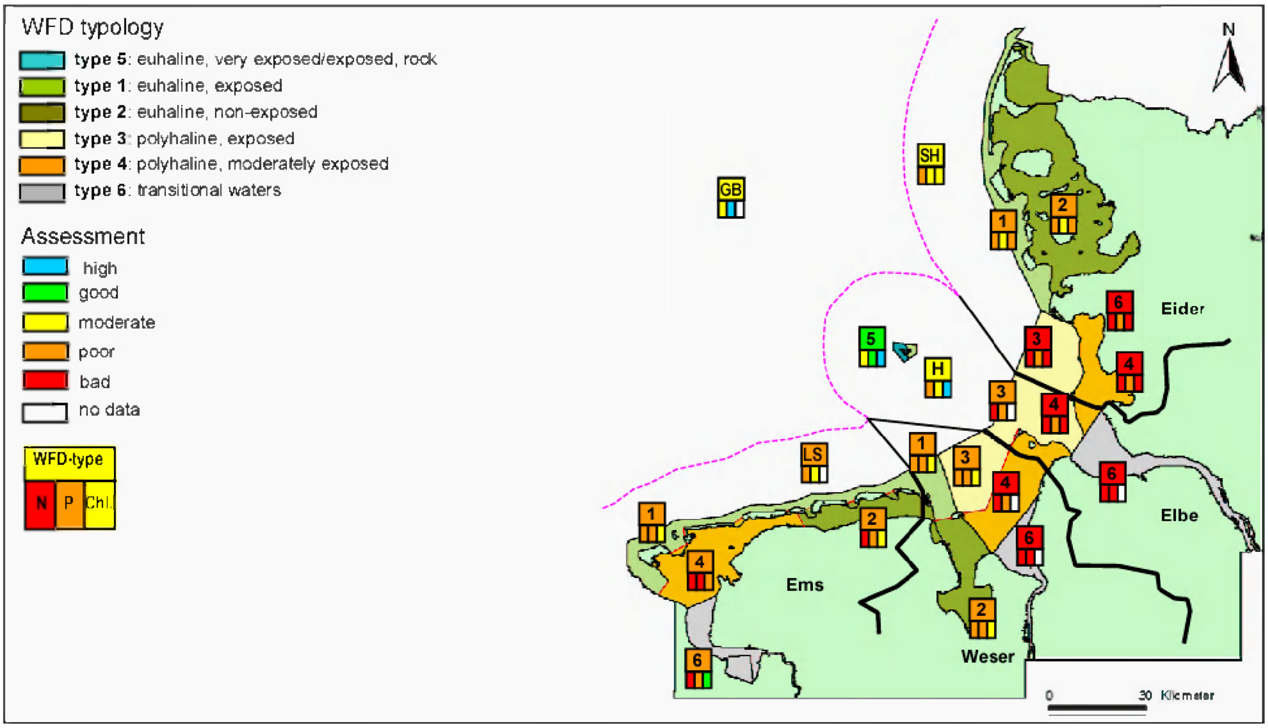

Figure 15. Compilation in the German coastal water of classes used for the OSPAR and Water Framework Directives. Numbers in relation to the corresponding catchment area indicates the types. Letters are indicating the different offshore waters. SH = Schleswig-Holstein, H = Helgoland, LS = Lower Saxonia, GB = German Bight.

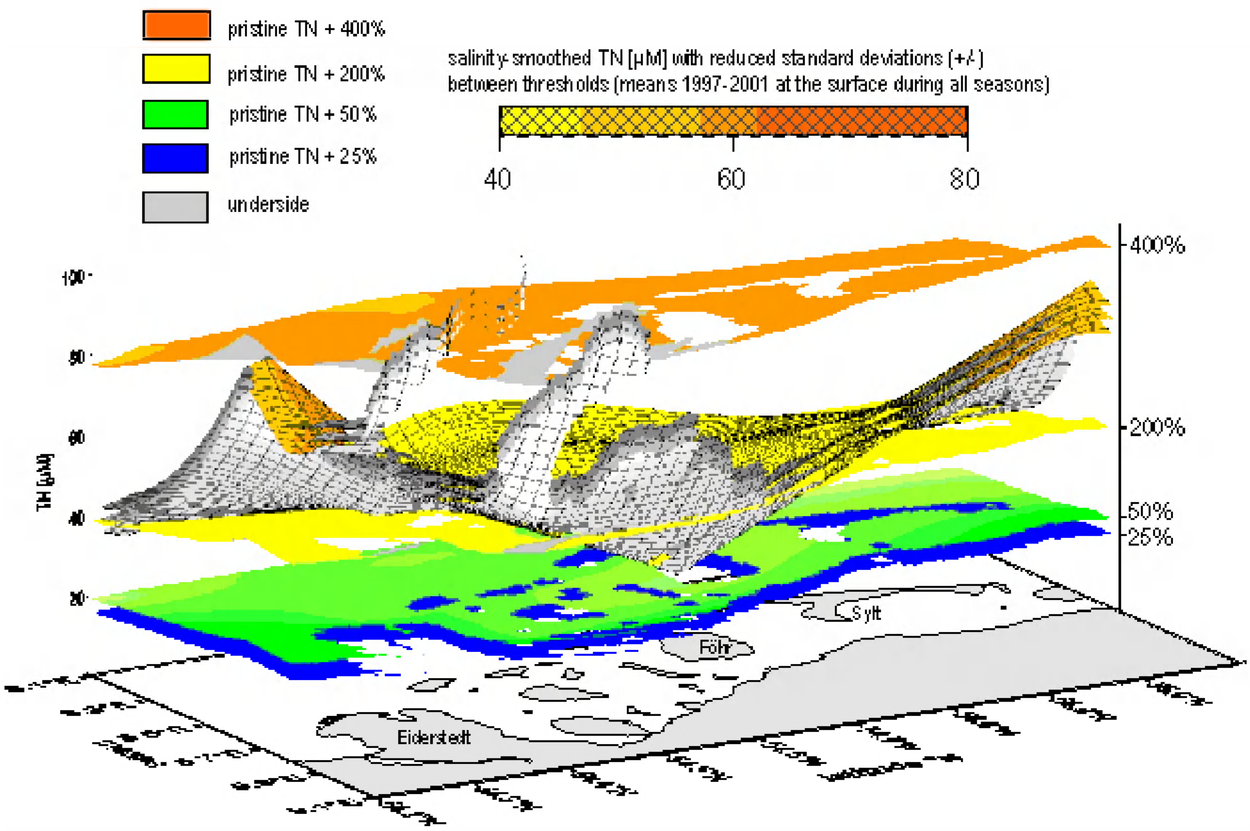

Figure 16. Salinity-smoothed TN (µM) with reduced standard deviations (+/-) between thresholds in the North Frisian Wadden Sea, map view to Northwest.

Tett et al 2003, Udy et al. 2005). However, it should be considered that also TN and TP show seasonal cycles, caused by denitrification or interaction with the sediment. For these reasons background concentrations and the deduced thresholds are reflecting always ranges.

Base of assessment

For the assessment the most recent 5-years time period was chosen for which data are available. A 5-year reporting schedule was proposed by OSPAR. The period between 1997 – 2001 has the advantage to perform an assessment without supplementary research data which have been used in the past to fill up data gaps (Brockmann et al. 2004). The restriction to monitoring data allows an evaluation of the ongoing monitoring in relation to the presented assessment.

The precision of any assessment is dependent on the quality of monitoring data which can be defined by the distance between sampling stations and frequencies. The quality of monitoring data should be considered for the scoring as well. By simple inventories the achieved resolution of present monitoring can be shown (Fig. 3 and 4). From these figures it can be estimated that the sampling is mostly restricted to the WFD-area, indicated by the black line on the map in Fig. 3 and 4, and that the chlorophyll sampling is performed only at a few stations. The same holds for the East Frisian coast where mostly only 10 samplings/5 years for TN, TP and chlorophyll have been performed between the islands. Only for the estuary of the Ems more than 200 TN and TP data were available and for the station at Norderney more than 180 chlorophyll measurements have been performed. For this reason the assessment is only locally valid and for larger areas the final classification must be assumed to be worse than deduced alone from the differences between recent data and historical background concentrations.

In the Wadden Sea which is frequently interacting with the water masses offshore (Dick et al. 1999, Pohlmann et al. 1999), the few samples which have been taken are not representative. Especially for the WFD-assessments of the small defined Waterbodies indicated by dotted lines on the maps in Fig. 3 and 4, the sampling coverage is not sufficient. On the other hand, for the assessment of the larger Types (Eider 1 – 4), the resolution may be representative due to the fast exchange of water masses between the tidal basins.

The frequencies of chlorophyll sampling with more than 20 data/month, aimed for the detection of nuisance species within the combined Types Eider 1 and 2 from May to September, are providing a good data base also for the general assessment of phytoplankton biomass (Fig. 12). However, the sampling during March and April, when the phytoplankton spring bloom is occurring, was less frequent and probably significant maxima have not been detected. Maximum chlorophyll values are assessed by OSPAR because they reflect bloom events. However, it must be considered that the chlorophyll data do not reflect the phytoplankton biomass directly (i) due to the different relationships between chlorophyll and biomass (carbon) of different species and of the same species at different physiological state (Brockmann et al. 1999b) and (ii) due to the large amount of chlorophyll that can originate from microphytobenthos in the Wadden Sea (Cadee 1984). A differentiation can only be performed on the base of species quantification and parallel biomass estimation. Additionally, the maximum chlorophyll values are dependent from the number of available data. For this reason the estimated maxima represent probably too low values.

Besides of frequent measurements at the stations on the islands of Norderney, Helgoland and Sylt (List), also between Helgoland and the coast frequent measurements have been performed. But this is not the case for all discussed parameters. Generally this combined sampling strategy of data, frequent measurements at some points combined within areas which are less frequent sampled but with a sufficient spatial resolution, can provide significant data sets which allow assessments of processes in space and time. However, the representativity of the key station for the surrounding area and the connections with the gradients and events in the station net has to be evaluated. This has mostly not been done.

Assuming a sufficient intercalibration and good data quality, which has not been checked by this study, it is very helpful for a roughly check of data quality by correlation analyses when all basic parameters (salinity, temperature, nutrients, chlorophyll, suspended matter, secchi depth) are estimated parallel. This allows establishing relationships in time and space for the different interfering hydrological and biogeochemical processes. Since the correlations between salinity TN and TP as well as between TN and DIN, TP and phosphate, TN and chlorophyll were highly significant, it can be assumed that the data quality was sufficient.

Classification

The proposal for the thresholds between the classes defined by OSPAR and WFD was made on the basis of (i) the suggestions by OSPAR (EUC 2005), allowing "elevated" concentrations of 50% above background, (ii) a sufficient differentiation of WFD-values (0.25 – 0.8, corresponding to 400 – 25% deviation from background) which were calculated by division of 100% as background by values, expressed as achieved levels (%), and (iii) considering the range of surpassing the background concentrations by modern data (Fig. 14). The thresholds in relation to background conditions may be changed in the future, because opposite to the scientifically based estimation of natural background data, the definition of thresholds includes also political elements considering the costs of possible measures to reduce eutrophication.

Even the OSPAR threshold of 50% above background is under discussion, because serious effects have been observed already by nutrient values at only 25% above background concentrations (Andersen et al. 2004). For the differences of effect-levels different regional hydrodynamic conditions are responsible, such as light conditions and residence times. These facts have to be considered within harmonised international assessments.

For the assessment according to the WFD, nutrients have only to be considered, if the biological elements are classified at least as "moderate" (COAST 2002, ECOSTAT 2004). However, nutrients are the causative factors, generating eutrophication and affecting all biological elements. Any measure to improve the trophic state of the ecosystem has to start with reduction of nutrients. For this reason nutrients are important assessment parameters for the Wadden Sea, too, and nutrients are assessed similarly to chlorophyll. This parallel assessment allows a direct comparison of scores.

Since the scores, indicated by the colours blue to red, are for the different parameters generally similarly distributed along the coastal water (Fig. 6 – 11), the assessment appears to be consistent and similar to that performed in 2003 for the German Bight during 1985 – 1998 (EUC 2003). However, for a final classification of the recent time period (1997 – 2001) the uneven distribution of data has to be considered for regional scoring. Indeed there are some discrepancies between the means of different seasons. For instance, TN was scored as moderate in a part of North Frisian area during all seasons, whereas DIN during winter was scored as poor (Fig. 6 and 8). The reasons are probably the high river loads of DIN during winter with extended plumes reaching at dominating westerly wind forces also the North Frisian Wadden Sea. Differences between scores of phosphate concentrations at the coast of Schleswig-Holstein for the period 1996 – 2001 are caused by the data from 1996, originating from a research project, by which during winter a local bloom event around the island of Föhr was detected (Brockmann et al. 2004).

The largest differences were observed between scores of TP and phosphate (Fig. 7 and 9): For the North Frisian area TP was generally scored as moderate during all seasons and phosphate during winter as poor. In the opposite, in the East Frisian area TP was scored between poor and bad and phosphate only as moderate. The nutrient loads from the Rhine include in this latter area less phosphate which has already been converted to phosphoric compounds like dissolved organic phosphorus and particulate phosphorus. The particulate material is kept close to the coast by the estuarine circulation (Postma 1984), resulting in high contributions to TP during spring (Brockmann et al. 1999a). Generally TP concentrations were higher along the East Frisian coast during spring and summer. In the opposite, during winter the contribution of phosphate to TP was only around 50% in this area.

Especially the estuaries have bad scores regarding nutrients, with concentrations surpassing mostly 400% of estimated background concentrations. For chlorophyll there are no data in the estuaries, but using the correlation between chlorophyll and salinity, "salinity-smoothed data" have been calculated for the measured salinity means (Fig. 3 and 10). Since the differences between the measured and calculated smoothed data were not significant in the coastal water, the more extended smoothed data have been presented.

Since for the calculation of smoothed data, light limitation and effects to the phytoplankton by salinity gradients were neglected, especially for the estuaries this scoring is questionable and has not been involved in the final compilation of classification (Fig. 15). This example shows again how important consistent data sets are for all assessed areas.

Due to the limitation of chlorophyll data only a restricted assessment for chlorophyll maxima could be performed. This resulted to some extent in a similar assessment as for mean chlorophyll (Fig. 10 and 11). It is remarkable that at locations with a high sampling activity (Fig. 3, at Norderney 185 samples were processed) the scoring of chlorophyll maxima resulted in poor (Norderney) or bad scores (Sylt). This indicates an insufficient frequency of sampling at most of the other locations where phytoplankton bloom events may not have been detected properly. Especially, for chlorophyll maxima it is evident that the scoring results depend on the frequency of sampling.

Opposite to the significant reductions of nutrient loads in the river discharges and concentrations within the estuaries,(ETG/MON 2004) there are no significant indications from the available data for changes in the well sampled North Frisian Types Eider 1 and 2 for the mean concentrations of TN, TP and chlorophyll (Fig. 12 and 13). Similar findings were also produced by ecosystem modelling, showing that only minor changes have been occurred in the coastal water in spite of significant nutrient reductions (Lenhart 2001). The reason is obviously the buffering capacity of the system, including the nutrient reservoirs of the sediment (van Beusekom et al. 1999), besides of the ongoing precipitation of nitrogen from the atmosphere which is especially high near the coast (Schulz et al. 1999). However, for some areas of the Wadden Sea and the TN load of Rhine and Meuse significant correlations have been identified with mean summer chlorophyll concentrations (van Beusekom et al. 2001, 2005). Also for the Sylt Römö Bight a decreasing trend of summer chlorophyll correlates with TN loads of Rhine/Meuse and Elbe/Weser (van Beusekom et al. 2005).

Due to the limitation of available data, environmental factors have mostly been neglected for the assessments of the single parameters. Only the variability, mainly caused by changing extensions and directions of river plumes, coupled with changing salinities, has been excluded. The spatial differences between original data and salinity-smoothed data are relatively small and caused only at some locations different classifications. However, the original hydrodynamic controlled variability destroys nearly every clear assessment result, if not only the means are considered. Since the natural hydrodynamic variability has not to be assessed, the procedure of "salinity-smoothing" was applied and is recommended.

This procedure, considering salinity related means and the remaining residual variability (Fig. 5), results in a clear separation between thresholds and recent data (Fig. 16). The distances between recent data and thresholds are made visible by this 3D-plot which results correspond to Fig. 6. The standard deviations for the thresholds, which may be transferred from the background values, were also mostly below 10% and were not considered in the figure for simplification. The original standard deviations for the modern TN data with ranges of 30 – 100% in the Wadden Sea (Fig. 5) would cause a strong overlapping with thresholds between the whole scale from high to low scores.

From the classification results some suggestions for the monitoring may be deduced: Assuming a precision of 10%, monitoring distances should generally cover this range in space and time. This means that (i) equidistant sampling within a station grid should maintain distances of 10% of the maximum extension of the area to be assessed or (ii) 10% of regular sampling times within a time period of 100% possible dates for events. However, for small areas, like the WFD-types or WFD-water bodies in the Wadden Sea, the limitation of minimum distances may be in the range of the extension of tidal tracks within the tidal channels, which are in the range of 10 nm. (Dick et al. 1999).

Since this would require an increase of monitoring activity, some reasons to reduce frequencies or to increase the necessary distances are mentioned:

- if the data are below the background level, only low monitoring activities are required,
- if the concentration differences between stations (gradients) are < 10%, a less spacial resolution is needed,
- if the differences with thresholds are high, a less sampling resolution is possible, as long as the the differences allow a significant classification,
- another impact is the residence time, if this is low, as is the case in many tidal basins (Dick et al. 1999), the spacial resolution of sampling may be reduced in favour of an increased frequency.

However, short time and small-scaled events should be considered for the monitoring design as well. Any evaluation and change of monitoring programmes should be accompanied by research activities, providing information about the representativity of locations and time sequences, according to the nesting principle (Brockmann et al. 1997).

The improvement of assessments is mainly based on a sufficient or better monitoring. The progress of both is an iterative process.

For a final classification the different representativities of regional data or parameters should be considered by weighting the scores. Insufficient data may be a reason to reduce the original scores following the precautional principle, because events with strong effects (e.g. nuisance blooms) may have been missed.

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References

Andersen, J. H., Conley, D. J. & Hedal, S. 2004: Palaeoecology, reference conditions and classification of ecological status: the EU Water Framework Directive in practice. - Marine Pollution Bulletin 49: 283-290.

Behrendt, H., Bach, M., Kunkel, R., Opitz, D., Pagenkopf, W.-G., Scholz, G. & Wendland, F. 2003: Internationale Harmonisierung der Quantifizierung von Nährstoffeinträgen aus diffusen und punktuellen Quellen in die

Oberflächengewässer Deutschlands. (In German with an English summary: Nutrient emissions into river basins of Germany on the basis of a harmonised procedure.) - UBA-FB 000446, Texte 82/03, 201 pp.

Beukema, J.J., Cadée, G. C. & Dekker, R. 2002: Zoobenthic biomass limited by phytoplankton abundance: evidence from parallel changes in two long-term data series in the Wadden Sea. - Journal of Sea Research 48: 111-125.

Brockmann, U.H. & Eberlein, K. 1986: River input of nutrients into the German Bight. - In: Skreslet, S. (Ed.): The role of freshwater outflow in coastal marine ecosystems. Springer-Verlag, Berlin: 231-240.

Brockmann, U.H., Raabe, T., Nagel, K. & Haarich, M. 1997: Measurement strategy of PRISMA: design and realisation. - Marine Ecology Progress Series 156: 245-254.

Brockmann, U., Raabe, T., Hesse, K., Viehweger, K., Rick, S., Starke, A., Fabiszisky, B., Topcu, D. & Heller, R. 1999 a: Seasonal budgets of the nutrient elements N and P at the surface of the German Bight during winter 1996, spring 1995, and summer 1994. - Deutsche Hydrographische Zeitschrift 51: 1-24.

Brockmann, U., Viehweger, K., Raabe, T., Rick, S., Rick, H.J., Heller, R. & Topcu, D. 1999 b: Conversion of nutrients in the Elbe river plume during drift experiments in the German Bight during spring 1995 and summer 1994. - Deutsche Hydrographische Zeitschrift 51: 293-312.

Brockmann, U.H. & Topcu, D. 2003: Natural reference concentrations of nutrients, organic matter and phytoplankton in the German Bight/North Sea (OSPAR – Area): Compilation, deduction and application. - Interim „May" report, ca. 70 pp.

Brockmann, U., Topcu, D. & Schütt, M. 2004: Bewertung der Eutrophierungsituation (Nährstoffe und Phytoplankton) zur Umsetzung der WRRL in den Übergangs- und Küstengewässer an der Westküste Schleswig-Holsteins. (In German with an English summary: Assessment of eutrophication (nutrients and phytoplankton) in transitional and coastal waters according to WFD along the west coast of Schleswig-Holstein.). - LANU Bericht, Hamburg 2004, 69 pp. + 50 Figs.

Cadée, G.C. 1984: Has input of organic matter into the western part of the Dutch Wadden Sea increased during the last decades? - Netherlands Institute Sea Research Publication Series 10: 71-82.

Cloern, J. E. 2001: Our evolving conceptual model of the coastal eutrophication problem. - Marine Ecology Progress Series 210: 223-253.

COAST 2002: Guidance on typology, reference conditions and classification systems for transitional and coastal waters. - CIS-WG 2.4, Copenhagen, 136 pp.

Dethlefsen, V. & von Westernhagen, H. 1982: Sauerstoffmangel in der Deutschen Bucht und seine Wirkung auf Fische und Bodenfauna. – Informationen für die Fischwirtschaft 29: 177-185.

Dethlefsen, V. & von Westernhagen, H. 1983: Oxygen deficiency and effects on bottom fauna in the eastern German Bight 1982. – Meeresforschung 30: 42-53.

Dick, S., Brockmann, U. H., Van Beusekom, J.E.E., Fabiszisky, B., George, M., Hesse, K.-J., Mayer, B., Nitz, T., Pohlmann, T., Poremba, K., Schaumann, K., Schönfeld, W., Starke, A., Tillmann, U. & Weide, G. 1999: Exchange of matter and energy between the Wadden Sea and the coastal waters of the German Bight - estimations based on numerical simulations and field measurements. - Deutsche Hydrographische Zeitschrift 51: 181-219.

Dyer, M.F., Fry, W.G., Fry, P.D. & Cranmer, G.J. 1983: Benthic regions within the North Sea. - Journal of Marine Biological Association of the United Kingdom 63: 683-693.

ECOSTAT 2004: Report for Eutrophication Steering Group; ECOSTAT WG 2.A, version 2.4, Review of eutrophication in European water policy & Conceptual Framework. - hamill_k@wrcpl.co.uk, 56 pp.

EUC 2003: Assessment Criteria for Eutrophication Areas - Emphasis German Bight - , Submitted by Germany, EUC 03/2/Info.2-E, OSPAR Commission, London, 10 pp.

ETG/MON 2004: Eutrophication Monitoring in the German Bight, Presented by Germany, ETG/MON 04/3/2-E, OSPAR Commission, London, 39 pp.

EUC 2005: Draft Proposal for an Agreement on the Eutrophication Monitoring Programme. - EUC 05/3/2, OSPAR Commission, Berlin, 4 pp.

Hargrave, B.T. & Peer, D.L. 1973: Comparison of benthic biomass with depth and primary production in some Canadian east coast inshore waters. - ICES Manuscript C.M. 1973/E: Shellfish and benthos committee, 14 pp.

Hedin, L. O., Armesto, J.J. & Johnson, A.H. 1995: Patterns of nutrient loss from unpolluted old-growth temperate forests: Evaluation of biogeochemical theory. - Ecology 76: 493-509.

Heip, C.H.R., Goosen, N.K., Herman, P.M.J., Kromkamp, J., Middelburg, J.J. & Soetaerd, K. 1995: Production and consumption of biological particles in temperate tidal estuaries. – Oceanography and Marine Biology: an Annual Review 33: 1-149.

Howarth, R.W., Billen, G., Swaney, D., Townsend, A., Jaworski, N., Lajtha, K., Downing, J.A., Elmgren, R., Caraco, N., Jordan, T., Berendse, F., Freney, J., Kudeyarov, V., Murdoch, P. & Zhu Zhao-Liang 1996: Regional nitrogen budgets and riverine N & P fluxes for the drainages to the North Atlantic Ocean: Natural and human influences. - Biogeochemistry 35: 75-139.

Laane, R. W. P. M. (Ed.) 1992: Background concentrations of natural compounds in rivers, sea water, atmosphere and mussels. - Tidal Waters Division, The Hague, 84 pp.

Lenhart, H.-J. 2001: Effects of river nutrient load reductions on the eutrophication of the North Sea, simulated with the ecosystem model ERSEM.- Senckenbergiana Maritima 31: 299-311.

Meybeck, M. 1982: Carbon, Nitrogen, and Phosphorus transport by world rivers. - American Journal of Science 282: 401-450.

Nielsen, S.L., Sand-Jensen, K., Borum, J. & Geertz-Hansen, O. 2002 a: Depth colonisation of eelgrass (Zostera marina) as determined by water transparency in Danish coastal waters. - Estuaries 25: 1025-1032.

Nielsen, S.L., Sand-Jensen, K., Borum, J. & Geertz-Hansen, O. 2002 b: Phytoplankton, nutrients, and transparency in Danish Coastal Waters. - Estuaries 25: 930-937.

Nixon, S.W. 1995: Coastal Marine Eutrophication: A Definition, Social Causes, and Future Concerns. - Ophelia 41: 199-219.

Pätsch, J. & Lenhart, H.-J. 2004: Daily loads of Nutrients, Total Alkalinity, Dissolved Inorganic Carbon and Dissolved Organic Carbon of the European Continental Rivers for the Years 1977-2002.- Berichte aus dem Zentrum für Meeres- und Klimaforschung, Reihe B, 159 pp.

Pearson, T.H. & Rosenberg, R. 1978: Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. - Oceanography and Marine Biological Annual Review 16: 229-311.

Pohlmann, T., Raabe, T., Doerffer, R., Beddig, S., Brockmann, U., Dick, S., Endgel, M., Hesse, K.-J., König, P., Mayer, B., Moll, A., Murphy, D., Puls, W., Rick, H.-J., Schmidt-Nia, R. & Schönfeld, W. 1999: Combined analysis of field and model data: A case study of the phosphate dynamics in the German Bight in summer 1994. - Deutsche Hydrographische Zeitschrift 51: 331-353.

Postma, H. 1984: Introduction to the symposium on organic matter in the Wadden Sea. -Netherlands Institute for Sea Research Publication Series 10: 15-22.

Rachor, E. 1980: The inner German Bight - an ecologically sensitive area as indicated by the bottom fauna. - Helgoländer Meeresuntersuchungen 33: 522-530.

Rachor, E. 1990: Changes in sublittoral zoobenthos in the German Bight with regard to eutrophication. - Netherlands Journal of Sea Research 25: 209-214.

Schulz, M., van Beusekom, J., Bigalke, K., Brockmann, U.H., Dannecker, W., Gerwing, H., Graßl, H., Lenz, W., Michaelsen, K., Niemeier, U., Nitz, T., Plate, E., Pohlmann, T., Raabe, T., Rebers, A., Reinhardt, V., Schatzmann, M., Schlünzen, K.H., Schmidt-Nia, R., Stahlschmidt, T., Steinhoff, G. & von Salzen, K. 1999: The atmospheric impact on fluxes of nitrogen, POPs and energy in the German Bight. - Deutsche Hydrographische Zeitschrift 51: 133-155.

Tett, P., Gilpin, L., Svendsen, H., Erlandsson, C. P., Larsson, U., Kratzer, S., Fouilland, E., Janzen, C., Lee, J.-Y, Grenz, C., Newton, A., Ferreira, J. G., Fernandes, T. & Scory, S. 2003: Eutrophication and some European waters of restricted exchange. - Continental Shelf Research 23: 1635-1671.

Tillmann, U., Hesse, K.-J. & Colijn, F. 2000: Planktonic primary production in the German Wadden Sea. - Journal of Plankton Research 22: 1253-1276.

Topcu, D., Brockmann, U. H. & Behrendt, H. 2006 (in prep.): Gradients of natural background concentrations of eutrophication indicators in German transitional and coastal waters at the North Sea.

Udy, J., Gall, M., Longstaff, B., Moore, K., Roelfsema, C., Spooner, D.R. & Albert, S. 2005: Water quality monitoring: a combined approach to investigate gradients of change in the Great Barrier Reef. - Australian Marine Pollution Bulletin 51: 224-238.

van Beusekom, J.E.E., Brockmann, U.H., Hesse, K.-J., Hickel, W., Poremba, K. & Tillmann, U. 1999: The importance of sediments in the transformation and turnover of nutrients and organic matter in the Wadden Sea and German Bight. - Deutsche Hydrographische Zeitschrift 51: 245-266.

van Beusekom, J.E.E., Fock, H., de Jong, F., Diel-Christiansen, S. & Christiansen, B. 2001: Wadden Sea specific eutrophication criteria. - Wadden Sea Ecosystem No. 14, Common Wadden Sea Secretariat 2001, 116 pp.

van Beusekom, J., Bot, P., Göbel, J., Hanslik, M., Lenhart, H.-J., Pätsch, J., Peperzak, L., Petenati, T. & Reise, K. 2005: Eutrophication. - In: Essink, K., Dettmann, C., Farke, H., Laursen, K., Lüerßen, G., Marencic, H. & Wiersinga, W. (Eds.); Wadden Sea Quality Status Report 2004, Wadden Sea Ecosystem No. 19 – 2005, 141–154.

van Raaphorst, W., de Jonge, V. N., Dijkhuizen, D. & Frederiks, B. 2000: Natural background concentrations of phosphorus and nitrogen in the Dutch Wadden Sea. RIKZ, The Hague, 53 pp.

Zevenboom, W. 1994: Assessment of eutrophication and its effects in marine waters. - Deutsche Hydrographische Zeitschrift Supplement 1: 41-170.

Mapping groundwater discharge and assessing the attenuation of groundwater nitrate at a site in the Wadden Sea

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In this paper the hydrogeological and geochemical aspects of the discharge of nitrate containing groundwater is presented for a study site in the northern Wadden Sea (Ho Bay, Denmark). Geophysical investigations using geo-electrical methods both onshore and offshore together with pore water sampling revealed a highly heterogeneous discharge of fresh groundwater out through the intertidal zone. The upper groundwater of the studied catchment contains nitrate concentrations up to 1 mM (mmol/L). However, the groundwater discharging into the sea is generally free of nitrate, except for a few local discharge zones with high nitrate concentrations. Denitrification apparently reduces the flux of nitrate from the coastal aquifer towards the marine environment. Geochemical analysis of flow paths in the groundwater aquifer indicates that nitrate reduction takes place within the groundwater aquifer and the upper surface sediment layer of the intertidal zone. In the groundwater zone nitrate is reduced by the oxidation of pyrite (FeS_2) and sedimentary organic matter, whereas in the intertidal zone sediments the oxidation of organic matter becomes increasingly important. The content of organic matter and pyrite in the sediment of the groundwater zone was found to be small, thus limiting the reduction capacity for nitrate in the groundwater zone. The future consequence of this may be an increase in the nitrate flux towards the marine environment.

Key words: Denitrification, geochemistry, geophysics, monitoring, nitrate, sub-marine groundwater discharge

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Introduction

Past studies of nutrient loadings to the coastal zone have primarily focused on the contribution from rivers and streams. The quantity of nutrients reaching the sea by direct groundwater discharge is poorly known (Conley et al. 2000, Burnett et al. 2003, Slomp & Van Cappellen 2004). While streams and rivers are easily identified and monitoring of their nutrient fluxes relatively straight forward, the identification of zones of direct groundwater discharge and their flux of nutrients is more challenging. For instance, is the direct groundwater discharge for a particular coastline occurring through a diffuse zone along the coast or is the majority of the discharge through discrete vents in the seafloor? Determining the mode of groundwater discharge and locating the major discharge zones thus becomes the first objective.

Geo-electrical methods measuring subsurface resistivity appears promising for mapping the sub-seafloor distribution of freshwater, due to the large resistivity contrast between seawater and freshwater. Geo-electrical techniques employing streamers towed after a boat has the potential for rapid mapping of large areas as opposed to point sampling of pore water (Zektzer et al. 1973, Lee 1985, Lavoie et al. 1988 and Vanek & Lee 1991). However, studies of the sub-seafloor distribution of freshwater saturated sediments utilising geo-electrical methods appear to be rare. In addition most surveys employed a single probe measuring the seawater conductivity or the resistivity of the uppermost layer of the sediment (Zektzer et al. 1973, Lee 1985, and Vanek & Lee 1991). Although the foundations for offshore resistivity measurements were laid decades ago (Zektzer et al. 1973, Lagabrielle & Teilhaud 1981 and Lagabrielle 1983), the application of the Underwater Multi-Electrode Profiling (UMEP) technique of this study to a marine environment, must therefore be considered novel.

The groundwater nitrate content has been increasing steadily over the past 30-40 yrs in northern Europe (Spalding & Exner 1993, Iversen et al. 1998). For coastal areas it is therefore reasonable to expect that the groundwater derived load of nitrate towards the marine environment will also increase. Given the high residence time of groundwater in aquifers (mostly 50-200 years) and because the coastal discharge zone is located at the end of the flow system, the full effect of discharging nitrate-rich groundwater into the marine environment may yet be years ahead. Furthermore, geochemical processes within the aquifer may effectively attenuate nutrients or altogether remove them from the groundwater, notably nitrate removal by denitrification (Postma et al. 1991, Tesoriero et al. 2000, Puckett et al. 2002). The discharge of nitrate free groundwater in the coastal zone may therefore well be a consequence of several factors: the groundwater age (e.g. groundwater infiltrated before the time of intensification of fertilizer application), spatial varying land use, natural nitrate reduction, or a combination hereof. Geochemical analysis of dissolved redox-species and dissolved gasses in the discharging groundwater may be used as a tool to unravel these questions (Postma et al. 1991, Blicher-Mathiesen et al. 1998 and Appelo & Postma 2005). Additionally it can be used to estimate the nitrate load, the degree of nitrate removal by denitrification and identify the electron donors responsible for the nitrate removal.

This paper describes some aspects of the geophysical mapping of groundwater discharge into the Wadden Sea and an assessment of the geochemical attenuation of nitrate in the coastal aquifer. Focus of the paper is on giving a broad overview of some of the qualitative aspects of the employed geophysical and geochemical methods. A more in-depth quantification of groundwater and nitrate fluxes will appear in Andersen et al. a) (in prep.). The results are part of the EC FP5 project NAME: Nitrate from Aquifers and influences on carbon cycling in Marine Ecosystems (NAME project website: http://name.er.dtu.dk). The field site was located in the northern Wadden Sea adjacent to Ho Bay, Denmark (Fig. 1).

Figure 1. Location of the study site (in the Wadden Sea).

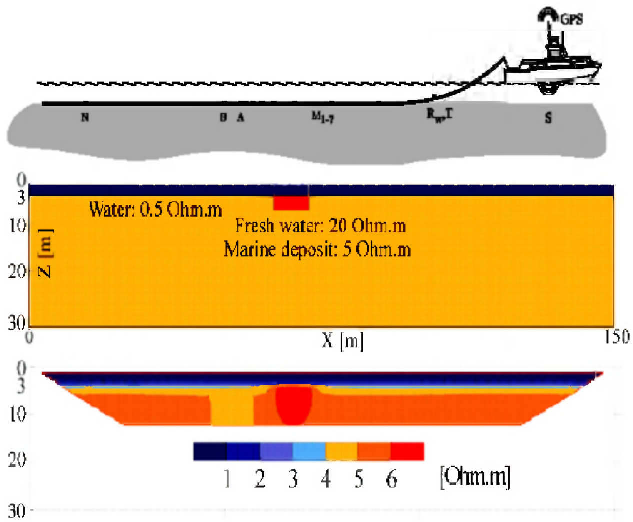

Figure 2. Top: UMEP methodology. On the towed array A and B are current emitting electrodes; N and M1-7 are potential electrodes; T and RW are temperature and seawater resistivity probes; and S are a depth sonar. The position is continuously recorded by GPS. Middle: A hypothetical seabed showing a freshwater body residing in a marine deposit covered by 3 m of seawater. Bottom: Theoretical resistivity response of the UMEP survey.

Materials and Methods

Underwater multi-electrode profiling (UMEP)

The UMEP method employs an array of electrodes towed along the seabed after a boat (Fig. 2). Electrical coupling to the seabed is ensured by the highly conductive seawater. The array is 110 m long with two current electrodes emitting current up to 10 A at 0.2 Hz. The resulting potential field is measured by eight potential electrodes arranged with one electrode 50 m away on one side of the current electrodes and the remaining 7 electrodes on the opposite side of the other current electrode with logarithmical increasing distances. Measurements were done every 1/10 of a second. Continuous measurements were made of the boat location (by GPS), the depth (by sonar), seawater conductivity and temperature.

The theoretical depth of penetration for a homogeneous half space depends of the array type and is about 1/5 to 1/4 of the spacing between the two most external electrodes i.e. a penetration depth of 22 to 28 m (Barker 1989). For a saline homogeneous half space below a seawater layer the depth of penetration reduces to about 1/15 of the total array length, giving a penetration depth of about 7 m. For measurements over freshwater saturated sediments the depth of penetration could increase to up to 25 m. However these simple rules do not apply to a heterogeneous resistivity distribution. Nevertheless the further apart the potential electrodes are from the current electrodes the deeper the measurement penetrates the seabed and the more sensitive the method is in detecting sediments containing freshwater. It is estimated that horizontal surface heterogeneities smaller than 1 m (smallest electrode separation) directly beneath the array can not be resolved. Furthermore the resolution decreases away from the array both vertically and laterally (Barker 1989).

The inversion of the UMEP data was done by a code developed specifically for the employed array configuration. Data was interpreted assuming a 3-layer model. Layer 1 is surface seawater with resistivity fixed by the conductivity probe measurements; layer 2 is surface sediment of varying depth and resistivity; and finally layer 3 is infinitely deep with varying resistivity. The inversion is done for each position along the array. To produce more continuous inverted results laterally along the array, the result of an inversion at a given position is used as the initial condition for the inversion process at the following position.

Multi-electrode profiling (MEP)

MEP was used to map the subsurface geology and on the beach and tidal flats additionally the distribution of fresh and saltwater in the subsurface. The method employs a long array of steel electrodes inserted into the ground with an electrode spacing varying from 1 to 5 m depending on the targeted measuring depth (see Dahlin 1996). An IRIS SYSCAL 48 instrument was used for the measurements. The measured apparent resistivities were inverted using the RES2DINV software (Loke & Barker 1996) to produce a calculated resistivity distribution of the subsurface.

Pore water sampling on the tidal flat

In the intertidal zone of the beach pore water samples were extracted from the sediment using a drive point technique, giving profiles of the upper 1.2 m of the pore water electrical conductivity (EC) and nitrate content. Steel pipes of 1.5 to 2 m in length (0.01 m outer diameter) were in one end fitted with a section of 0.05 m with holes and an outer mesh of polyethylene (PE). The end of the steel pipe was fitted by a pointed PE-tip. The steel pipes were driven into the sediment by a battery powered handheld drilling machine with percussion. At desired depth suction was applied to the pipe by a 60 ml syringe and a 3-way valve. The pipe was flushed with the equivalent of three pipe volumes. EC was measured in a small beaker with a WTW LF-196 conductivity meter and a WTW Tetracon 96 EC probe. The nitrate content was measured using analytical test strips (Merckoquant, range 10-500 mg/L).

Installation of monitoring wells

Permanent monitoring wells were installed at different depth along two transects parallel to the groundwater flow, from the upper beach and out into the intertidal zone. The wells were constructed of either a 0.025 or 0.032 m outer diameter PE pipe and at the bottom fitted with a single 0.12 m section screened with a PE mesh. A Geoprobe 54 DT drill-rig was used to install the well to depths of up to 10 m below the surface.

Groundwater sampling and analysis

From the permanent monitoring wells groundwater samples were extracted by a gas-lift technique using nitrogen gas (see Andersen et al. 2005 and Fetter 1993 for details). The wells were flushed three times and then sampled. A flow cell equipped with probes for O_2, pH and EC (electrical conductivity) was directly mounted on the sampling tube. Dissolved O_2 was measured using a WTW EO 196-1,5 electrode connected to a WTW OXI 196 Oximeter. EC was measured with a WTW Tetracon 96 EC probe and a WTW LF-196 conductivity meter. pH was measured with a WTW SenTix 41 electrode connected to a WTW 196 pH-meter. Samples for all other parameters were filtered through a 0.2 µm Satorius Minisart filter. Samples for the nitrate and sulphate content were frozen and later analysed using Ion Chromatography (HPLC) using a Vydac 3021IC column. Alkalinity was determined in the field by the Gran titration method (Stumm & Morgan 1981). Dissolved ferrous iron (Fe^{2+}) was also measured in the field by the spectrophotometric Ferrozine method (Stookey 1970). Dissolved inorganic carbon (DIC) was calculated on the basis of the measured alkalinity and pH.

Sampling of dissolved gasses

For the sampling of dissolved gasses (N_2, O_2, CO_2 and Ar) a cobber tube was lowered into the screened section of the monitoring wells and pumped, using a peristaltic pump, at a low rate to minimise the drawdown in the well. On the effluent side of the pump the groundwater was passed through a 'bubble-stripper' made of glass, where a gas bubble was equilibrated with the groundwater. After an equilibration period of minimum 20 min. the gas bubble was sampled through a septum using a glass-syringe and immediately analysed. One sub-sample was analysed for N_2, O_2 and Ar on a ML GC 82 gas chromatograph with a Shintzu C.B3A integrator, fitted with a 10 m Haye Sep A column and using helium as carrier gas. The column was cooled to about -20°C using dry ice for the effective separation of O_2 and Ar. CO_2 was determined on another sub-sample on a SRI 8610A gas chromatograph by Thermal Conductivity Detection.

Results and Discussion

Distribution of fresh groundwater at the coastline

The studied catchment at Ho bay, shown in Figure 3, is landwards limited by a groundwater divide located about 1400 m from the coast. No major streams are draining the catchment, so groundwater discharge at the shore face is the only mode for surplus groundwater to leave the aquifer. The aquifer consists of a buried valley cut into a thick Neogene clay deposit and filled with sandy sediments of Quaternary and Neogene age. Secondary buried channels connect the aquifer to the coast as seen on the southwest edge (lower left edge) of the 3D geological model in Figure 3.

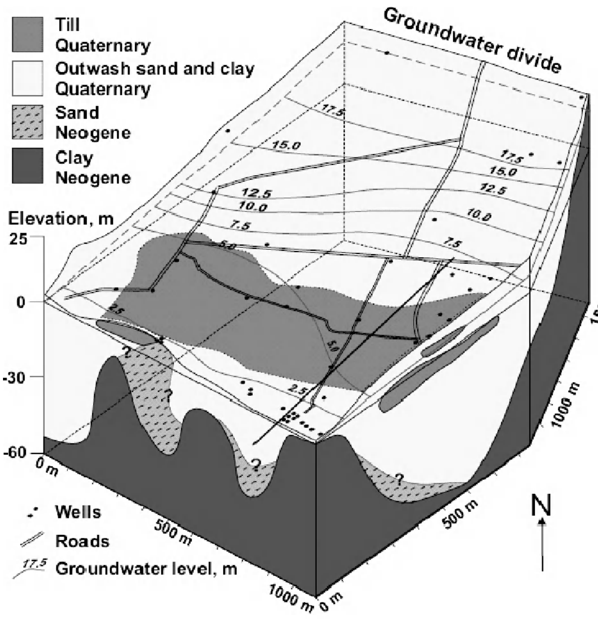

Figure 3. Geological 3D model for the study site. The southwest edge faces the Ho bay.

Figure 4 shows the calculated (or inverted) resistivity in the multi-electrode profile (MEP) done along the beach. The profile shows an upper zone of high resistivity separated by an undulating border from a deeper zone of low resistivity. The low resistivity (< 20 Ω-m) is, based on drillings, interpreted as the Neogene clay layer, but at some locations, it could also be caused by seawater saturated sandy sediments. The zones of high resistivity (30-500 Ω-m) are uniquely caused by freshwater saturated sediments and the secondary buried valleys are situated where these zones reaches deep into the profile (~40 m). Here the aquifer has a significant thickness of freshwater saturated sediments and thus a potentially high discharge of freshwater to the coast.

Figure 5a shows a map of the calculated resistivity of the second layer in the inverted UMEP-data. The map shows how the apparent resistivity varies offshore along the coast with the light grey areas representing a high resistivity, qualitatively indicating zones with freshwater residing in the seabed. These zones are indicated by arrows in Fig. 5a and correlate with the larger zones of high calculated resistivity from the MEP profile (indicated by arrows in Fig. 4).

The presence of freshwater in the seabed was verified by pore water sampling at low tide, measuring the electrical conductivity (EC) at 0.3 to 1.2 m below the sediment surface. This was done within the detailed study area of Figure 5b. Figure 6a show the pore water resistivity (the reciprocal of the EC values) at 0.3 m below the sediments surface with increasing resistivity to the south and landwards. The resistivity also increases with depth (not shown). Only a qualitative comparison of the pore water and UMEP resistivities can be made since the resistivity values derived from the pore water and the UMEP surveys are not directly comparable. This is partly because the pore water resistivity values do not include the effect of the sediment grains, and partly because the depth to the second layer of the UMEP interpretation is not well determined, as opposed to the depths of the pore water data. Despite this the distribution in the pore water resistivity largely confirms the freshwater distribution given by the UMEP (see Fig. 5b). The correlation between the two methods, although the values are not directly comparable, shows that the UMEP method is capable of detecting zones of freshwater saturated sediments within the seabed despite being done in the highly conductive seawater of the bay (resistivity ~ 0.3Ω-m).

The pore water measurements reveal a higher variability with local zones of low resistivity (Fig. 6a). These zones represent seawater present in the sediment near local layers and lenses of more clayey sediments. This shows that although the UMEP method gives a good overall idea of the distribution of freshwater, pore water sampling is necessary for accurately describing the actual freshwater discharge, mixing of sea- and freshwater and the associated chemical reactions.

Distribution of nitrate

The upper groundwater of the catchment generally contains nitrate in concentrations up to about 1 mM (mmol/L). In the groundwater discharging at the

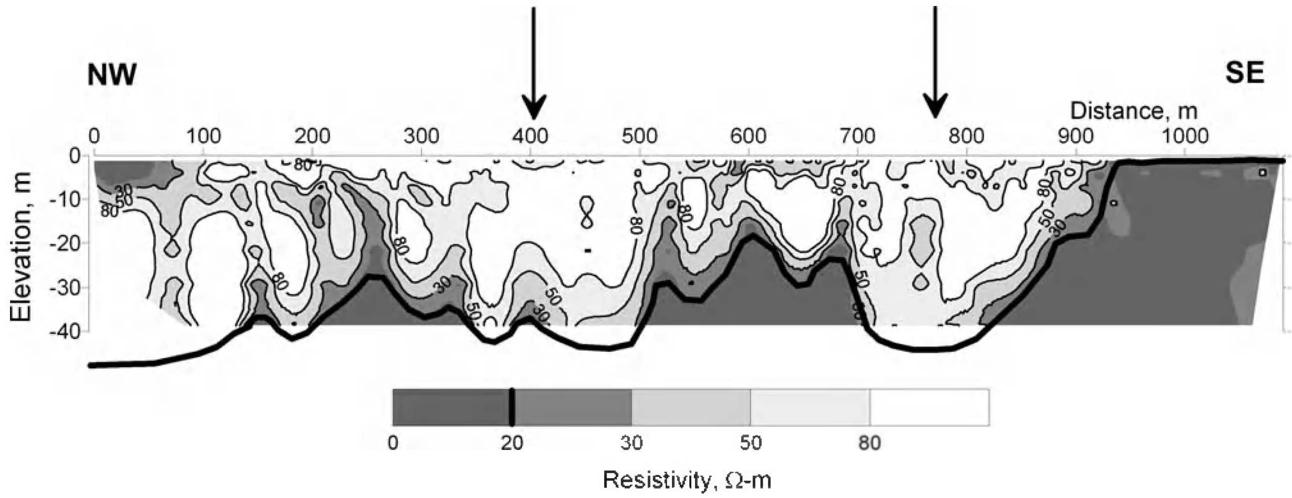

Figure 4. MEP profile along the beach of the study site showing the distribution of freshwater (30-500 Ω-m). Black line is an interpretation of the aquifer bottom and the arrows indicate the major zones of groundwater discharge.

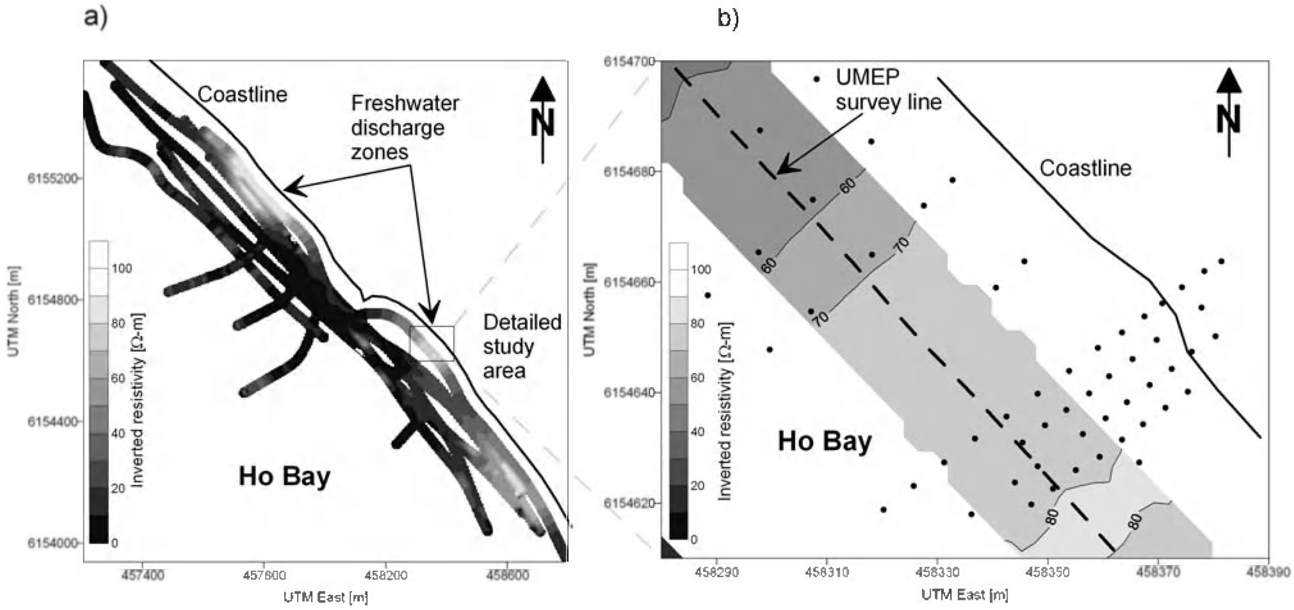

Figure 5. a) UMEP survey lines showing the contoured calculated resistivity (Ω-m) of the second layer of the inverted UMEP data. b) Detailed study area showing contoured calculated resistivity (Ω-m) of one UMEP survey line. Dots are locations for sampling of sediment pore water.

coastline nitrate was only detected at a few locations along the high tide line and only at a few of these; nitrate was found to reach into the intertidal zone. Such a zone is depicted in Fig. 6b which is the same zone as shown for the EC measurements of Fig. 6a. The nitrate concentration at 0.3 m below the sediment surface, reveals a plume of nitrate (up to 0.7 mM) reaching more than 30 m out into the intertidal zone (Fig. 6b). Just 10 meters to the north, nitrate containing groundwater is not emerging in the intertidal zone. A possible explanation for the lack of nitrate in the discharging freshwater of the intertidal zone may be the reduction of nitrate mediated by micro-organisms (denitrification). A way to investigate this is to study the geochemical evolution along a groundwater flow path.

Geochemical evolution along a flow path

Figure 7 shows the water chemistry in a 2D vertical transect (see location Fig. 6b) parallel to the groundwater flow, 10 m north of the nitrate plume of Fig. 6b. The groundwater flow direction was, inferred from head measurements, predominantly horizontal towards the sea with an upward component nearer to the coastline (indicated by the flow path arrow in Fig. 7a). A groundwater travel time of about 1 yr from 0 to 20 m in Fig. 7 was estimated for the flow path based on Darcy's law (Andersen et al. a) in prep.).

Along the flow path nitrate decreases from a maximum of 1.4 mM upstream to 0 mM downstream, near the high tide line (Fig. 7a). Concurrently an increase is seen in both sulphate (Fig. 7b), dissolved inorganic carbon (DIC) (Fig. 7c) and dis-

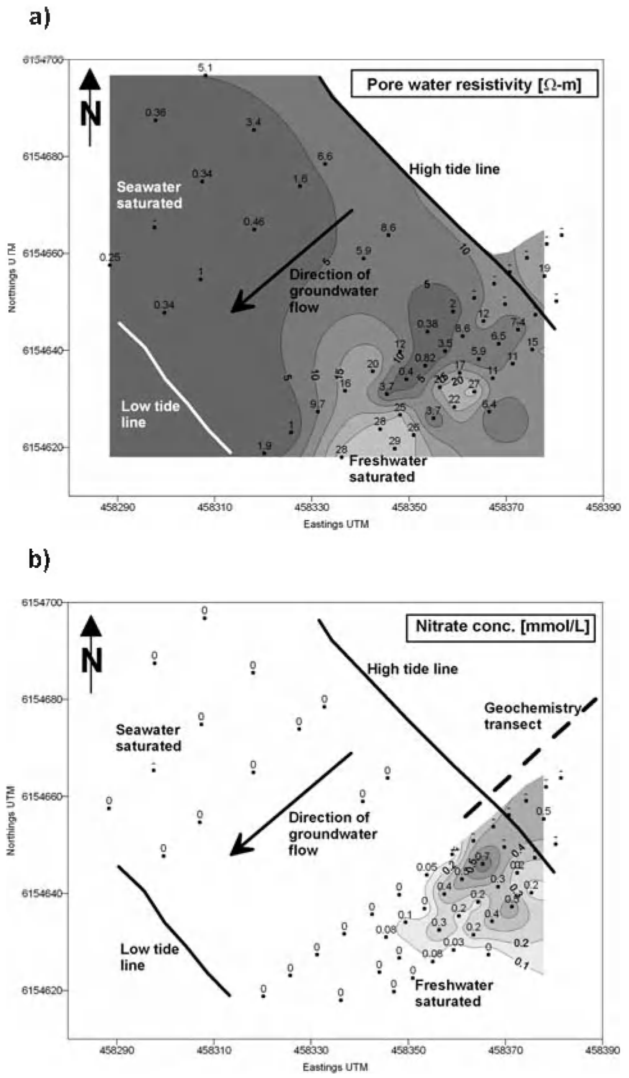

Figure 6. a) Pore water resistivity (Ω-m) based on the electrical conductivity of the pore water samples and b) nitrate distribution on the tidal flat. The dashed line in b) represents a transect of monitoring wells. Both plots cover the same area as in Fig. 5b.

solved ferrous iron (Fe^{2+}) (Fig. 7d). The increase in sulphate and Fe^{2+} indicate that oxidation of pyrite (FeS_2) may play a role in reducing the nitrate according to:

(1)

$$5FeS_2 + 14NO_3^- + 4H^+ \rightarrow 7N_2 + 5Fe^{2+} + 10SO_4^{2-} + 2H_2O$$

In reaction (1) the Fe^{2+} may be further oxidised to Fe^{3+} and precipitate as $Fe(OH)_3$. The increase in DIC (Fig. 7c) indicates that organic matter (CH_2O) also contributes to the reduction of nitrate according to:

(2)

$$5CH_2O + 4NO_3^- \rightarrow 2N_2 + 4HCO_3^- + CO_2 + 3H_2O$$

Both reactions (1) and (2) predict that nitrate is transformed into dinitrogen (N_2). The net nitrate removal by reactions (1) and (2) can uniquely be verified by measuring excess dissolved N_2 (Vogel et al. 1981). Because the background concentration of dissolved atmospheric N_2 may vary due to different processes during groundwater recharge (temperature, excess air etc. (Heaton & Vogel 1981)) argon (Ar) was used as an inert tracer.

Figure 7e shows the measured N_2/Ar-ratio in the transect. In the upstream nitrate rich zone the N_2/Ar-ratio varies between 70 and 90, roughly corresponding to the theoretical N_2/Ar-ratio of 81.8 in water equilibrated with the atmosphere at 8°C. Seawards, into the zone depleted in nitrate, the N_2/Ar-ratio increases to a maximum around 175. This supports that nitrate reduction releasing N_2 is taking place. From the measured N_2/Ar ratio the amount of excess N_2 was calculated using the method suggested by Blicher-Mathiesen et al. (1998). The N_2/Ar data suggests that the amount of nitrate reduced is up to 0.9 mM (Fig. 7f). This roughly equals the nitrate concentration measured in the upstream part of the transect (Fig. 7a). If the 0.9 mM NO_3^- were solely reduced by pyrite it should release 0.64 mM SO_4^{2-}, an increase somewhat higher than the maximum observed increase of 0.5 mM. It should be noted that this rough stoichiometric balance approach does not consider temporal variations in the nitrate concentration along the flow path or the diffusion of nitrate into the deeper flow paths. This may well explain the minor chemical imbalances between the up and downstream parts of the flow path.

To quantify the relative importance of pyrite and sedimentary organic carbon as electron donors in the reduction of nitrate, an electron balance (Postma et al. 1991) was set up along the flow path of Fig. 7a. In the electron balance the number of electrons that participate in a given redox-reaction is multiplied with the aqueous concentration of the relevant reactants or products (Table 1). The electron equivalents obtained in this way can be plotted cumulatively as in Figure 8. Sulphate was corrected for the sea-salt contribution, whereas the DIC was corrected for calcite dissolution. The DIC correction was done by assuming that excess Ca^{2+} (compared to the sea-salt contribution of Ca^{2+}) must largely come from dissolution of carbonate minerals, releasing an equivalent amount of DIC on a molar basis. The sum of electron acceptors, O_2 and NO_3^- in the upstream part of the flow path is roughly matching the downstream increase in the electron donors represented by sulphate and DIC. Pyrite appears to account for about 40% of the increase in the sum of sulphate and DIC whereas organic carbon is responsible for the remaining 60% (Fig. 8).

This raises the question of electron donor availability and the ability of the aquifer to buffer the nitrate load. The sedimentary organic carbon (TOC) and pyrite content was measured on sediment samples along the transect (Andersen et al. b) in prep.).

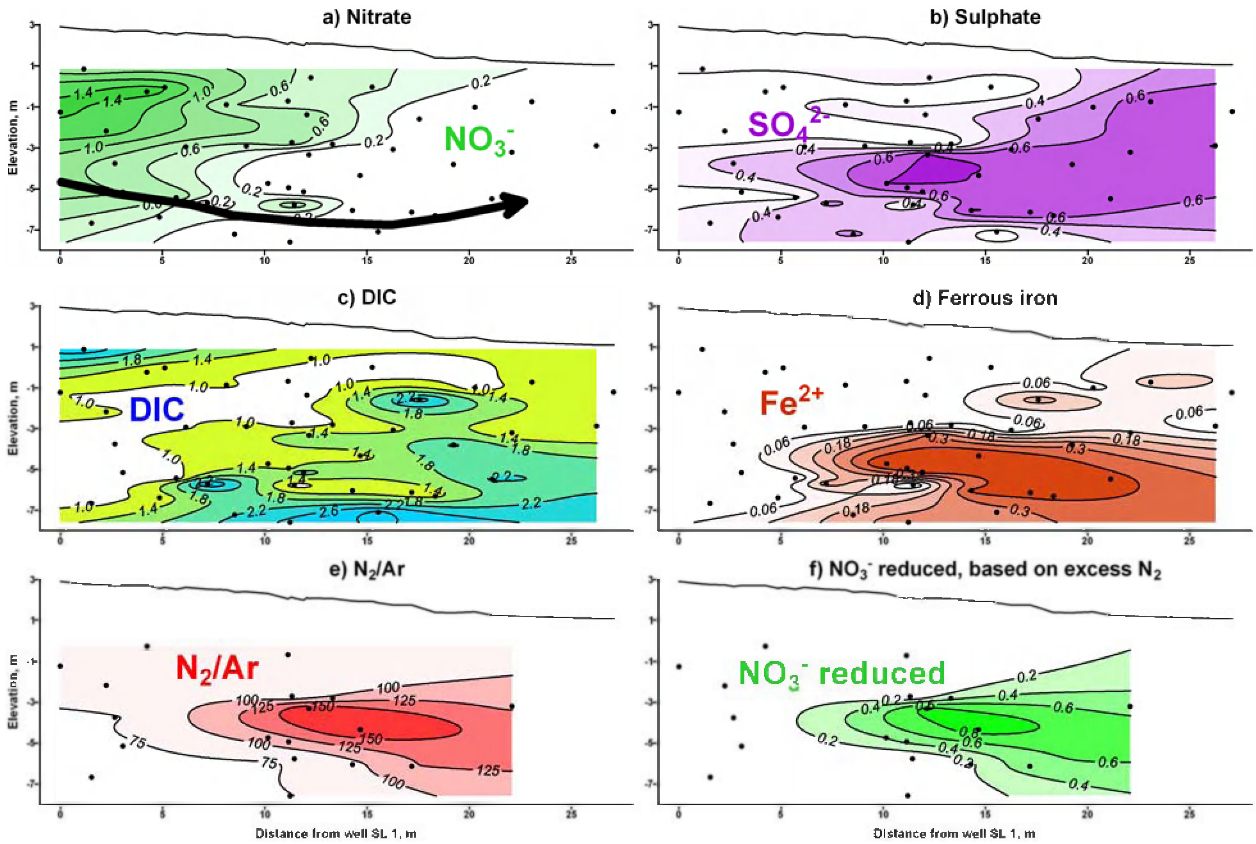

Figure 7. Vertical profiles along a transect showing distributions of a) nitrate (mM), b) sulphate (mM) corrected for sea-salt contribution, c) DIC (mM) corrected for sea-salt contribution and calcite dissolution, d) Ferrous iron (mM), e) the ratio of dissolved N_2/Ar, and f) the amount of nitrate reduced based on excess N_2 (mM). The dots are sampling points and the arrow in a) indicate a groundwater flow path.

Table 1. Principles for the electron balance calculations (from Postma et al. 1991).

Reaction	Transferred electrons	Electron equivalents
$S_{FeS2} \rightarrow SO_4^{2-}$	$-7e^-$	$7\cdot[SO_4^{2-}]$
$CH_2O \rightarrow CO_2$	$-4e^-$	$7\cdot[DIC]$
$Fe_{FeS2} \rightarrow FeOOH$	$-1e^-$	$\frac{1}{2}\cdot([SO_4^{2-}] - 2\cdot[Fe^{2+}])$
$NO_3^- \rightarrow \frac{1}{2}N_2$	$+5e^-$	$5\cdot[NO_3^-]$
$O_2 \rightarrow 2O^{2-}$	$+4e^-$	$4\cdot[O_2]$

The TOC was found to be evenly distributed, averaging 12.5 mmol C/kg (or 47 mmol C/L pore water), but the reactive fraction of this may well be much smaller (the remaining part being in a recalcitrant form, not readily available for the microorganisms). In light of the apparent importance of pyrite as an electron donor, it is surprising that the pyrite content is small ranging between 0.5-2.5 mmol S/kg (or 2-10 mmol S/L pore water). This shows that, at least in the studied portion of the groundwater aquifer, the electron donor pool is limited and can be expected to be exhausted.

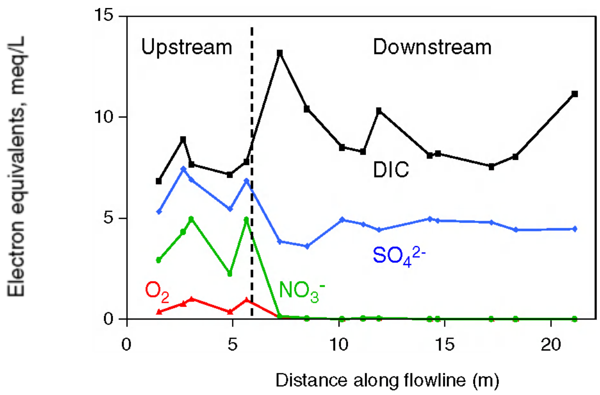

Figure 8. Electron equivalents plotted cumulatively along the flow path in Fig. 7a. The electron equivalents are calculated according to the scheme given in Table 1.

However, in the recent upper sediments (< 1 m) of the intertidal zone the TOC content is orders of magnitudes higher and appears to be more reactive than in the aquifer sediments and here the oxidation of organic matter becomes increasingly important in reducing the groundwater nitrate (Lavik et al. in prep.). This recent sediment layer may possibly retain a renewable reduction potential towards NO_3^- through exchange with the overlying seawater column.

Due to the very heterogeneous conditions at the study site, both in terms of the freshwater discharge and the nitrate distribution, a quantification of the groundwater nitrate flux on the regional scale of the Ho bay is highly uncertain based on these limited data. This said, a "back of the envelope" calculation indicates that the groundwater nitrate flux is probably orders of magnitude lower than the nitrate flux from the nearby river Varde Å.

Conclusions

The UMEP method was found to be fast and efficient for mapping the distribution of freshwater in the seabed of the intertidal zone. The method revealed a very heterogeneous discharge of fresh groundwater out through the intertidal zone.

The flux of nitrate towards the marine environment was likewise highly variable even over short distances along the coast. Although the upper groundwater of the catchment area is generally rich in nitrate, the direct discharge of nitrate rich groundwater occurred only at a few locations. The evolution in geochemistry along sampled flow paths indicates that currently nitrate is attenuated by denitrification before it reaches the marine environment and that pyrite and sedimentary organic matter are responsible for the nitrate reduction. However, the limited amount of pyrite and reactive organic matter in the aquifer sediments, and the fact that nitrate rich groundwater actually does discharge in some locations indicate that the reductive capacity of the aquifer sediments is limited. In the future the groundwater flux of nitrate towards the tidal zone sediments can be expected to increase, if agricultural practices are not changed. A general assessment of groundwater nitrate loads discharging to the coastal zone clearly needs careful consideration of the local variability in geology, hydrogeology and geochemistry.

References

Andersen, M.S., Nyvang, V., Jakobsen, R. & Postma, D. 2005: Geochemical processes and solute transport at the seawater/freshwater interface of a sandy aquifer. – Geochimica et Cosmochimica Acta 69: 3979-3994.

Andersen, M.S., Baron, L., Gudbjerg, J., Gregersen, J., Chapellier, D., Jakobsen, R. & Postma, D. a): Discharge of nitrate-containing groundwater into a coastal marine environment. Submitted to - Journal of Hydrology.

Andersen, M.S. Jakobsen, R. & Postma, D. b): Nitrate transport and reduction in a coastal aquifer. To appear in international scientific peer-reviewed Journal (Geochimica et Cosmochimica Acta or Groundwater).

Appelo, C.A.J. & Postma, D. 2005: Geochemistry, groundwater, and pollution -2nd ed. A.A. Balkema, Rotterdam, 649 pp.

Barker, R. D. 1989: Depth of investigation of collinear symmetrical four-electrode arrays: - Geophysics, Soc. of Expl. Geophys. 54: 1031-1037.

Blicher-Mathiesen, G., McCarty, G.W. & Nielsen, L.P. 1998: Denitrification and degassing in groundwater estimated from dissolved dinitrogen and argon. - Journal of Hydrology 208: 16-24.

Burnett, W.C., Bokuniewicz, H., Huettel, M., Moore, W.S. & Taniguchi M. 2003: Groundwater and pore water inputs to the coastal zone. - Biogeochemistry 66: 3-33.

Conley, D.J., Kaas, H., Møhlenberg, F. Rasmussen, B. & Windolf, J. 2000: Characteristics of Danish estuaries. - Estuaries 23: 820-837.

Dahlin, T. 1996: 2D resistivity surveying for environmental and engineering applications. - First Break 14: 275-283.

Fetter, C.W. 1993: Contaminant Hydrogeology. Macmillan Publishing Company, New York, 458 pp.

Heaton, T.H.E. & Vogel, J.C. 1981: "Excess air" in groundwater. - Journal of Hydrology 50: 201-206.

Iversen, T.M., Gant, R. & Nielsen, K. 1998: Nitrogen enrichment of European inland and marine waters with special attention to Danish policy measures. - Environmental Pollution 102: 771-780.

Lagabrielle, R. 1983: The effect of water on direct current resistivity measurement from the sea, river or lake floor. - Geoexploration 21: 165-170.

Lagabrielle, R. & Teilhaud, S. 1981: Prospection de gisements alluvionaires de sites aquatiques par profils continus de résistivité au fond de l'eau. - Bull. Liaison Labo. P. et Ch. 114: 17-24.

Lavik, G. et al.: Groundwater derived nitrate processing in a coastal marine sediment. To appear in international scientific peer-reviewed Journal (intended for Limnology and Oceanography).

Lavoie, D., Mozley, E., Corwin, R., Lambert, D. & Valent, P. 1988: The use of a towed, direct-current, electrical resistivity array for the classification of marine sediments. OCEANS '88. A Partnership of Marine Interests. Proceedings: 397-404.

Lee, D.R. 1985: Method for locating sediment anomalies in lakebeds that can be caused by groundwater flow. - Journal of Hydrology 79: 187-193.

Loke, M.H. & Barker, R.D. 1996: Rapid least-squares inversion of apparent resistivity pseudosections using a quasi-Newton method. - Geophysical Prospecting 44: 131-152.

NAME project website: http://name.er.dtu.dk

Postma, D., Boesen, C., Kristiansen H. & Larsen F. 1991: Nitrate reduction in an unconfined sandy aquifer: Water chemistry, reduction processes,

and geochemical modelling. - Water Resources Research 27: 2027-2045.
Puckett, L.J., Cowdery, T.K., McMahon, P.B., Tornes, L.H. & Stoner, J.D. 2002: Using chemical, hydrologic and age dating analysis to delineate redox processes and flow paths in the riparian zone of a glacial outwash aquifer-stream system. - Water Resources Research 38(8): 10.1029/2001WR000396.
Slomp, C.P. & Van Cappellen, P. 2004: Nutrient inputs to the coastal ocean through submarine groundwater discharge: controls and potential impact. - Journal of Hydrology 295: 64-86.
Spalding, R.F. & Exner, M.E. 1993: Occurrence of nitrate in groundwater – A review. - Journal of Environmental Quality 22: 392-402.
Stookey, L.L. 1970: Ferrozine – A new spectrophotometric reagent for iron. - Analytical Chemistry 42: 779-781.
Stumm, W. & Morgan, J.J. 1981: Aquatic chemistry. - 2nd ed. Wiley & Sons, New York, 780 pp.
Tesoriero, A.J., Liebscher, H. & Cox, S.E. 2000: Mechanisms and rate of denitrification in an agricultural watershed: Electron and mass balance along groundwater flow paths. - Water Resources Research 36: 1545-1559.
Vanek, V. & Lee, D.R. 1991: Mapping submarine groundwater discharge areas – an example from Laholm Bay, southwest Sweden. - Limnology and Oceanography 36: 1250-1262.
Vogel, J.C., Talma, A.S. & Heaton, T.H.E. 1981: Gaseous nitrogen as evidence for denitrification in groundwater. - Journal of Hydrology 50: 191-200.
Zektzer, I.S., Ivanov, V.A. & Meskheteli, A.V. 1973: The problem of direct groundwater discharge to the seas. - Journal of Hydrology 20: 1-36.

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Implementation strategy for monitoring of new hazardous substances

Susanne Boutrup

Boutrup, S. 2006: Implementation strategy for monitoring of new hazardous substances. In: Monitoring and Assessment in the Wadden Sea. Proceedings from the 11. Scientific Wadden Sea Symposium, Esbjerg, Denmark, 4.-8. April, 2005 (Laursen, K. Ed.). NERI Technical Report No. 573, pp. 83-87.

Monitoring of hazardous substances is included in TMAP (Trilateral Monitoring and Assessment Program), in the Danish Nationwide Monitoring and Assessment Programme NOVANA as wells as in the Water Framework Directive. Monitoring of hazardous substances in groundwater started in Denmark about ten years ago and was included in monitoring of point sources, air, fresh surface water and marine areas in 1998. The Danish approach in the future is only to include new hazardous substances in the monitoring programme if it has been documented to be relevant. A scheme for the documentation is set up including considerations about analytical methods and preliminary investigations. The preliminary considerations are primarily based on literature. The need for implementation of the list of priority substances in the Water Framework Directive (WFD) in the Danish part of TMAP is discussed in the current paper. The strategy is used as starting point for that discussion.

Key words: hazardous substances, strategy for implementing new substances, preliminary considerations

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Introduction

Monitoring of hazardous substances started up in Denmark about ten years ago with monitoring of pesticides in groundwater. In the previous Danish Environmental Monitoring Programme NOVA-2003 launched in 1998 monitoring of hazardous substances was included as a part of the programme (Danish Environmental Protection Agency, 2000). Monitoring of hazardous substances was included in monitoring of point sources including wastewater and sludge, fresh surface water in addition with sediment, biota and seawater from marine areas as well as continuation of monitoring in groundwater. In addition, heavy metals have been included in air monitoring since 1989.

NOVA-2003 was in 2004 followed by a revised National Monitoring and Assessment Programme for the Aquatic and Terrestrial Environments (NOVANA) (National Environmental Research Institute, 2005). The objectives of NOVANA are to:

- describe sources of pollution and other pressures and their impact on the status of the aquatic and terrestrial environments and identify trends
- generally document the effect of national action plans and measures directed at the aquatic and terrestrial environments – including whether the objectives are achieved and whether the trends are in the desired direction
- meet Denmark's obligations in relation to EU legislation, international conventions and national legislation
- contribute to enhancing the scientific basis for future international measures, national action plans, regional management and other measures to improve the aquatic and terrestrial environments, including contributing to develop various tools.

In 1998 it was not possible to measure a number of the hazardous substances included in NOVA-2003, since analytical methods could not meet the demands for detection limits, analytical uncertainty etc. It meant that some analyses could not be performed in the beginning of the programme period. Another experience from NOVA-2003 was that a number of substances were not detected at all with the used methods and detection limits. The experiences from monitoring of hazardous substances in NOVA-2003 resulted in the conclusion that new hazardous substances would only be included in the subsequent monitoring programme NOVANA if it had been documented to be relevant and within analytical range.

Method

The Danish implementation strategy for monitoring of new hazardous substances can be divided into three main topics: preliminary considerations based on literature, availability of analytical methods and preliminary investigations (fig. 1).

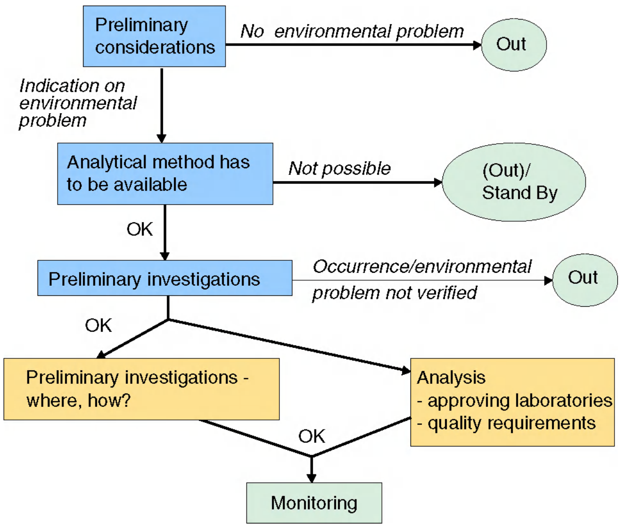

Figure 1. Stepwise approach of the Danish strategy of selecting hazardous substances for monitoring.

Preliminary considerations
In the preliminary considerations information is collected on use and chemical / physical data. Information about solubility and lipophility, persistency and tendency to bioaccumulate are especially important. In addition, any data on occurrence in the environment either within the country or in countries with comparable consumption and environmental conditions are included. This combined information can give a first indication on the presence of the substance in the environment and where it might be found. Besides, when the information is linked to knowledge about toxicology we might get indication on environmental effect.

If the conclusion of the preliminary considerations is that it is likely to find the considered substance in concentrations that might give effects in the environment, the next step has to be taken. It must be considered whether it is sufficient to focus separately on the substance, or if substances with similar characteristics or consumption pattern have to be included. This might be metabolites or substances within the same chemical group, e.g. other phthalates when DEHP is included. Alkylphenols is an example where the metabolic product, for example nonylphenol, nonylphenol-mono-ethoxylate and nonylphenol-di-ethoxylate should be expected to found in higher concentrations than the mother product nonylphenolpolyethoxylates (Danish Environmental Protection Agency, 1995).

Finally, the relevant concentration level must be considered to set up demands for analytical quality. If quality criteria exist, one tenth of those is normally used as demand for detection level. But if no quality criteria exist information about toxicology and consumption have to be used as normative.

Analytical methods
It is essential that analytical methods which meet the demands for detection levels and other quality criteria are available. Normally the analytical work in monitoring programmes is done by accredited laboratories, but since we are talking about analyses of new hazardous substances the analyses are normally not done routinely. For that reason laboratories accredited to the analysis might not exist. It means that it is essential to be even more careful when the demands for analytical quality and demands for documentation of the analytical quality are set up.

It is important that the demanded detection limit is below the concluded relevant concentration level. If the demanded detection level cannot be met we have to reconsider if it is relevant to analyze at all. Analyzing with too high detection limits or unreliable quality is waste of time and money.

As the preliminary considerations could result in inclusion of some extra substances, it is worthwhile considering whether the analytical method provides the opportunity to include additional substances with the same procedure, which renders the total set of analyses to be more easy and cheap. It is of course essential to bear in mind that data handling etc. requires resources.

Preliminary investigations
If the preliminary considerations end up with the conclusion that it might be relevant to include a new substance in the monitoring programme and that a suitable analytical method is available, the next step is to document that inclusion is relevant. We look more closely into that evaluation by a screening.
The screening should provide answers to the questions:

- Does the substance occur in the environment?
- If so, in which matrices does it occur?

To get the right answers the screening strategy has to be considered. Included in this is knowledge about the transport of the substance in the ecosystem as basis for considerations about sample matrices and sample locations. It is essential to include the matrices and locations, which are closest to the sources in order to get a positive reply on the first question. If the substance is not found close to the source, it might not be found at all. In addition matrices which are in different ecological distances from the source should be included in order to answer the second question. As an optimum the matrix, which are exactly so far away that the substance doesn't occur, should be included.

Furthermore, the considerations about the strategy also include considerations about sampling strategy. It is essential that the samples are as representative and reproducible as possible. From some matrixes the samples should be composite samples, e.g. samples of sludge, while from other matrixes the samples should be one spot sample, e.g. surface water samples. Wastewater samples should be flow or time proportional, implying that the substance in focus is not volatile.

The number of samples in the screening depends on how homogeneous the substance can be expected distributed. It is necessary to get enough results to be able to make reliable conclusions. Finally a possible seasonal effect has to be considered. Does the sampling time of the year have any influence on the results?

The preliminary investigations may end up with results on which it is concluded that it is not likely to find the substance in the environment in concentrations which give rise to effect, are in conflict with objectives or which exceed the quality criteria. In that case the substance would not be recommended to the monitoring programme. Alternatively, if recommended the substance would have to be included in the monitoring programme. Before the substance is included in the routinely run monitoring programme decisions about matrix, frequency, demands for analytical quality, selection of sampling stations etc. similar to the considerations done in relation to planning a screening have to be taken.

Using the strategy in TMAP revision

The Danish approach to implementation of new hazardous substances in the monitoring will be used in the process of implementing the Danish obligation according to TMAP as well as the Water Framework Directive.

The current list of priority substances in the Water Framework Directive consists of 33 substances (EU, 2001). 10 of these substances are included in the current TMAP monitoring. 14 of the remaining 23 substances are included in NOVANA, 10 in the marine sub-programme and 4 in other sub-programmes. This leaves 9 substances, which are included in neither TMAP nor NOVANA (fig. 2). Among these are 5 substances, which were included in NOVA-2003 resulting in the conclusion that further monitoring is not relevant. The final conclusion is according to the figure below that we don't have sufficient knowledge of 4 of the substances on the Water Framework Directive list of priority substances. In addition to that there were 4 substances of which we don't have knowledge concerning

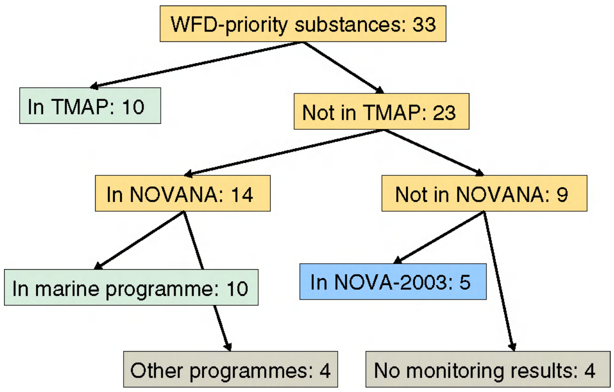

Figure 2. Number of substances on the Water Framework Directive list of priority substances in the TMAP-programme and in the Danish monitoring programmes NOVA-2003 and NOVANA.

occurrence in marine areas. Before implementation of these substances – or any other new hazardous substance - it should be documented that the implementation is relevant. The individual substances in each group are listed in Appendix 1.

Recommendation

When a programme including monitoring of hazardous substances is going to be revised it should be considered whether the monitoring of the current substances should be continued in the revised programme as well as if it is relevant to implement new hazardous substances. Exclusion of some "old" substances for which monitoring is not relevant any longer or for which the frequency could be reduced could give space for new activities. The revision and subsequent monitoring should be done according to the principle "need to know" not "nice to know".

References

Danish Environmental Agency (2000): NOVA-2003 (in Danish) Programbeskrivelse for det nationale program for overvågning af vandmiljøet 1998-2003. Redegørelsen fra Miljøstyrelsen No. 1.

National Environmental Research Institute (2005): NOVANA. National Monitoring and Assessment Programme for the Aquatic and Terrestrial Environment. Programme Description – Part 1. NERI Technical Report, No. 532.

Danish Environmental Agency (1995): Water Quality Criteria for Selected Priority Substances. Working Report No. 44.

EU (2001): Decision No. 2455/2001/EC of the European Parliament and the Council of 20 November 2001 establishing the list of priority substances in the field of water policy and amending Directive 2000/60/EC.

Appendix 1. Hazardous substances on the Water Framework Directive List of Priority Substances, TMAP (Trilateral Monitoring and Assessment Program), NOVANA (National Monitoring and Assessment Programme for the Aquatic and Terrestrial Environment) and NOVA-2003 (National Monitoring and Assessment Programme for the Aquatic Environment).

CAS nr.		WFD	TMAP	NOVANA	NOVA-2003
Metals					
7440-43-9	Cadmium and its compounds	x	x	ps,ms,mb	
7439-92-1	Lead and its compounds	x	x	ps,ms,mb	
7439-97-6	Mercury and its compounds	x	x	ps,ms,mb	
7440-02-0	Nickel and its compounds	x	x	ps,ms,mb	
Pesticides					
15972-60-8	Alachlor	x			
1912-24-9	Atrazine	x		mw	fw, gw
470-90-6	Chlorfenvinphos	x			
2921-88-2	Chlorpyrifos	x			
330-54-1	Diuron	x		mw	
115-29-7	Endosulfan	x			fw
608-73-1	Hexachlorocyclohexane	x	x	ms,mb	
34123-59-6	Isoproturon	x		gw,fw	
122-34-9	Simazine	x		mw, fw,gw	
1582-09-8	Trifluralin	x			fw
Alifatic hydrocarbons					
85535-84-8	C10-13-chloroalkanes	x			
Aromatic hydrocarbons					
71-43-2	Benzene	x		ps	
91-20-3	Naphthalene	x		ps,ms,mb	
Halogenated alifatic hydrocarbons					
107-06-2	1,2-Dichloroethane	x			ps,fw,mw
75-09-2	Dichloromethane	x		ps	
87-68-3	Hexachlorobutadiene	x		ps,ms	
67-66-3	Trichloromethane (Chloroform)	x		ps	
Halogenated aromatic hydrocarbons					
118-74-1	Hexachlorobenzene	x	x	ms,mb	
608-93-5	Pentachlorobenzene	x		ps, ms	
12002-48-1	Trichlorobenzenes	x		ms	
Polyaromatic hydrocarbons					
120-12-7	Anthracene	x	x	ps,ms,mb	
206-44-0	Fluoroanthene	x	x	ps,ms,mb	
n.a.	Polyaromatic hydrocarbons	x	x	ps,ms,mb	

Table is continued on the next page

CAS nr.		WFD	TMAP	NOVANA	NOVA-2003
Phthalates (softeners)					
117-81-7	Di(2-ethylhexyl)phthalate (DEHP)	x		ps,ms,mb	
Alkylphenols (nonionic detergents)					
25154-52-3	Nonylphenols	x	x	ps,ms	
1806-26-4	Octylphenols	x			fw
Brominated flameretardents					
n.a.	Brominated diphenylether	x		ps,ms,mb	
Chlorophenols					
87-86-5	Pentachlorophenol	x		ps, gw, fw	fw,gw
Organotin compounds					
688-73-3	Tributyltin compounds	x		ms,mb	

fw: freshwater, gw: ground water, mw: marine water, ms: sediment, mb: biota, ps: point sources

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Macrophytes in the western Wadden Sea: monitoring, invasion, transplantations, dynamics and European policy

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Historic surveys of seagrass beds in the Dutch Wadden Sea were made in 1869, 1931 and 1972/1973. Annual quantitative analysis during 1995-2004 of seagrass-monitorings showed that the beds are highly dynamic. In the Balgzand area (western Wadden Sea), a dominance of eelgrass (*Zostera marina*) was recorded in the 1930s, followed by a dominance of dwarf eelgrass (*Zostera noltii*) in the 1970s. At present, the area is dominated by low densities of widgeon grass (*Ruppia maritima*), that has invaded the area in 2002 approximately. This sequence of macrophytes might be correlated to increasing soil level due to sedimentation (GIS-analysis of monitoring in 1930s, 1970s and 2000s), but a changed salinity regime may also have been of influence. Near the seaward edge of the *Ruppia* bed, reintroduced dwarf eelgrass (planted in 1993) and eelgrass (planted in 1999, 2003 and 2004) lead a vulnerable existence. The highly variable survival rates underline the importance of spreading of risks of reintroduction programmes, both in time and space. This spreading of risks is also a general population strategy of *Zostera*, and the resulting high population dynamics imply that a large buffer zone around the beds should be protected to allow for new colonisations. This is recommended to be included in EU directives.

Key words: Invasions, monitoring, policy, population dynamics, seagrass, trend analysis, water plants

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Introduction

Seagrass has played an important role in The Netherlands. Until the early twentieth century, hundreds of families earned a living from the collection and harvesting of the robust form of eelgrass that grew around Low Tide level (LT) or deeper. It was used as isolation and filling material, and until the eighteenth century also for dike construction. Due to its former economic importance, historic maps of seagrass distribution from 1869 and 1931 are available (Oudemans et al. 1870, Reigersman et al. 1939). In the early 1930s, the robust form of eelgrass disappeared from the Wadden Sea. This was attributed to a seagrass disease, the closure of the Zuiderzee, two subsequent years of sunshine deficit or a combination of those three (Giesen et al. 1990a,b, den Hartog 1996). In the early 1970s, den Hartog & Polderman (1975) inventoried intertidal seagrass beds in the

Dutch Wadden Sea (dwarf eelgrass and the remaining flexible form of eelgrass). From 1995 onwards (and incidentally in previous years), seagrass beds are monitored on a yearly basis in the Dutch Wadden Sea by the Department of Public Works within the framework of the biological monitoring program (www.zeegras.nl). In 2002, widgeon grass colonised an area of more than 200 ha in the western Wadden Sea, in low densities (less than 1% cover). In this area, seagrasses got extinct in the mid 1970s. Since water clarity improved at the end of the 1980s, possibilities for reintroduction were investigated and transplantations were carried out in 1993, 1998, 2003 and 2004.

In this paper we will relate water plant distribution to location depth (tidal height) using maps from the 1920s onward, to gain insight in the depth distribution of the species eelgrass (two forms), dwarf eelgrass and widgeon grass in the western Dutch Wadden Sea (Balgzand). Secondly, we will analyse the dynamics of natural populations, and thirdly, we will summarise the transplantation results. This will lead to a number of policy recommendations.

Water plants at Balgzand 1931-2002

At Balgzand, in the westernmost part of the Wadden Sea, vegetation was mapped in 1931 by both Reigersman et al. (1939) by boat, and by Harmsen (1936) by foot, presumably also in 1931, or in 1932, the paper is not clear about this. In 1972, den Hartog and Polderman (1975) mapped the area, and in 2002 it was mapped again by van 't Veer, after the invasion of a new species in the area, widgeon grass (Figures 1 and 2).

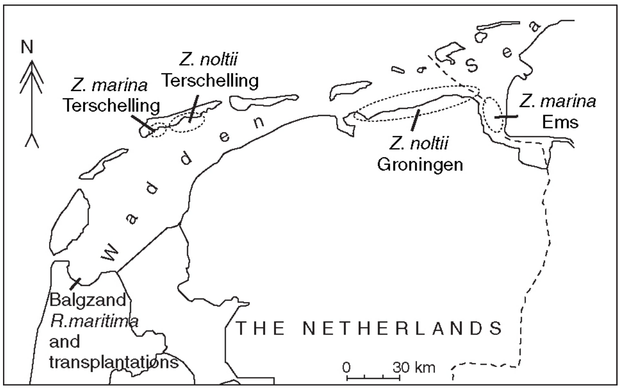

Figure 1. Map showing the Dutch Wadden Sea with present locations of seagrass beds.

The maps were digitised by ArcMap 8.2. These distribution maps were related to tidal depth maps from the Ministry of Transport, Public Works and Water Management. These maps were made by sounding from a boat, and have an accuracy of ± 0.10 m. Tidal depth data were used for the period 1926–1934, 1971–1974, and 1997-2002. Tidal depth maps were converted from ASCII to grid using ArcToolbox 8.2, and subsequently to feature by a spatial analyst (ArcMap 8.2). Grids were 20x20 m.

In the 1930s, in the Wadden Sea, but also in the Thames estuary, the following zonation of *Zostera* species was encountered: in the highest (shallowest) zone dwarf eelgrass occurs, followed by a zone of the flexible form of eelgrass, an un-vegetated zone and a zone of the robust form of eelgrass (Wohlenberg 1935, Harmsen 1936, van Katwijk et al. 2000). In the Balgzand area, Reigersman et al. (1939) and Harmsen (1936) only mapped the eelgrass beds (Fig. 2a and b). Note the difference in areas mapped in 1931/2 by Reigersman et al. (1939) and by Harmsen (1936). The difference is probably due to the different aims and methods: Reigersman et al. had an economical interest, i.e., only in the robust type eelgrass growing around LT and deeper, and mapped the area from a boat; Harmsen (1936) had a botanical interest, and mapped the area by foot and omitted water covered areas (see Fig. 3).

In the 1970s both species of seagrass were mapped (Polderman & den Hartog 1975), dwarf eelgrass appeared to have been slightly dominant over eelgrass. In 2000, for the first time, a few widgeon grass patches had been discovered at Balgzand by Rob Dekker (personal communication), who frequents this area at least yearly since mid-1990's. In 2002 and 2004, 225 and 264 ha of widgeon grass were recorded, respectively (Groeneweg 2004a). Densities were less than 1%. The sequence of water plant species was correlated to tidal depth (Fig. 3).

During this period, the investigated area silted up due to sedimentation, resulting in decreased tidal depths (Table 1). The optimal depth ranges of the water plants in the Dutch Wadden Sea and particularly Balgzand are listed in Table 2, and visualised in Figure 3. Most of the seagrass beds mapped in the western Wadden Sea in 1931 were located subtidally with an optimum depth of around 1 m below MSL (Mean Sea Level) or 0.4 m below LT (Table 2 and 3).

This corresponds with recordings of Feekes (1936 in de Jonge & de Jong 1992). Ninety percent of the seagrass beds were located subtidally. This contrasts with the 44% that de Jonge & Ruiter (1996) calculated on the basis of nautical maps. Perhaps this difference is due to the unavailability of the detailed bathymetric maps at the time of de Jonge and Ruiter's study. Of interest is the higher optimum of the seagrass beds at Balgzand in comparison to the total Wadden Sea, MSL -0.7 versus -1.0 m, respectively (Table 2 and 3). When related to low tide level, the difference is less: LT -0.20 and -0.40 m, respectively. The zone with maximum cumulative wave dynamics roughly corresponds with these depths (van Katwijk & Hermus 2000). Further analysis of the maps in relation to exposure to waves and currents, and in relation to

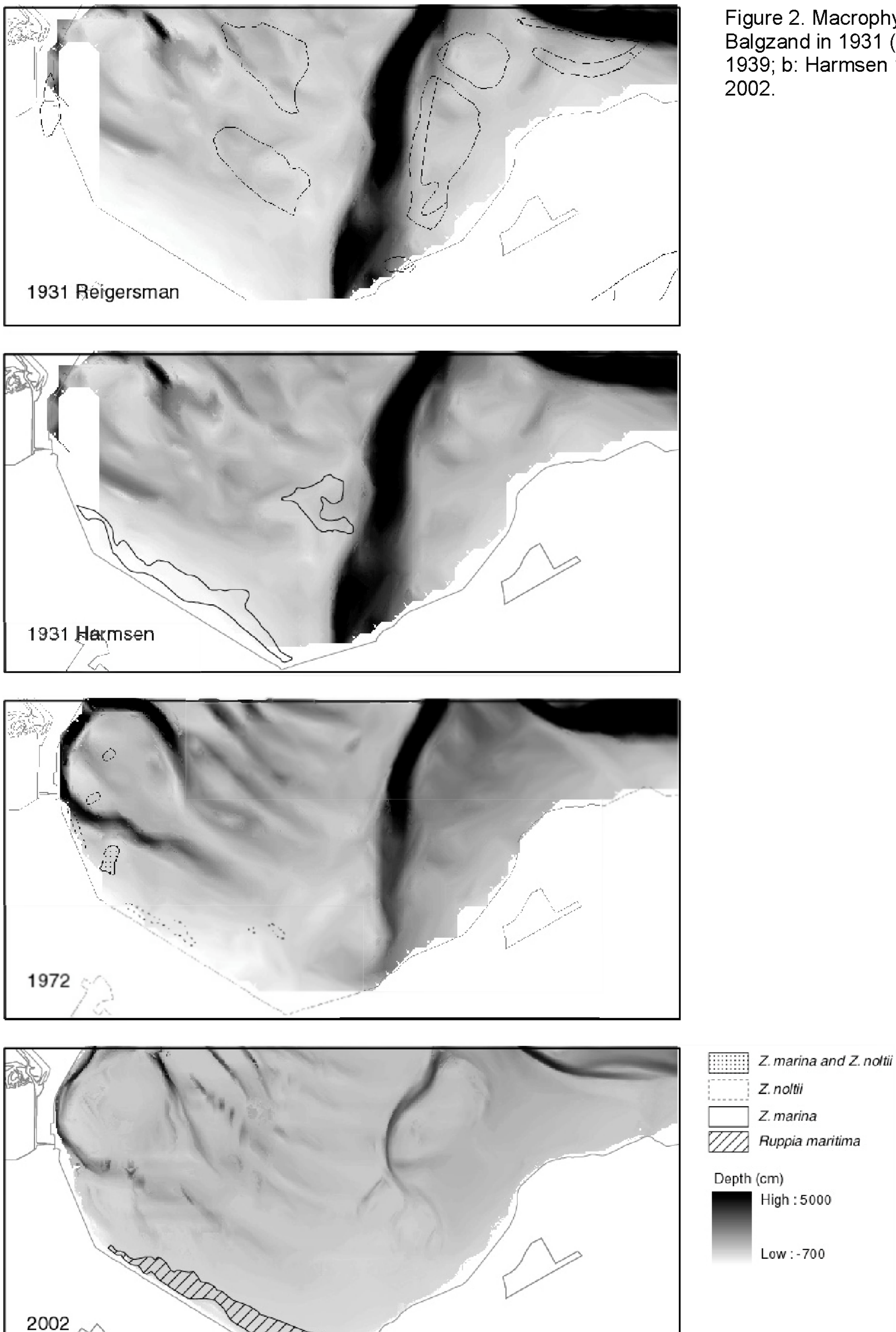

Figure 2. Macrophyte distribution at Balgzand in 1931 (a: Reigersman et al. 1939; b: Harmsen 1936); c: 1972 and d: 2002.

available substratum at each depth level, could offer explanations for the depth distribution of the seagrass beds in the 1930s.

The unvegetated zone that was found during the 1930s at several locations in the Wadden Sea, but also in the Thames estuary (Harmsen 1936, van Katwijk et al. 2000), appeared to have been located between MSL –0.25 and –0.4 m in the Balgzand area. This depth range of the un-vegetated zone as derived from the GIS analysis of seagrass and bathymetric maps, is consistent with field observations noted in literature, i.e. circa -0.20 below MSL and one or two decimetres above LT (van Goor 1920, Wohlenberg 1935, Harmsen 1936, Klok & Schalkers 1980, Boley 1988, van Katwijk & Hermus 2000). This consistency between the notes of eye-witness-scientists and the calculations performed in this study indicates that the data used and the analyses are suffici ently reliable, notwithstanding the inaccuracies in the sounding method and positioning.

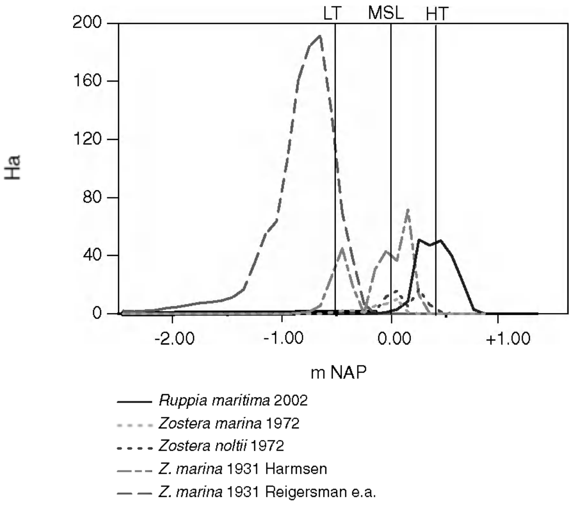

Figure 3. Depth distribution of water plants in Balgzand in 1931 mapped by Reigersman et al. (1939) and by Harmsen (1936), in 1972 mapped by den Hartog and Polderman 1975 and in 2002 by R. van 't Veer (unpubl.). LT: Low tide level, MSL: Mean Sea Level, HT: High tide level (Klok & Schalkers 1980).

Table 1. Depth distribution of the coastal zone of Balgzand compared between the 1930s, 1970s and 2000s. In this GIS-analysis we selected grid cells that (a) had *Ruppia maritima* present in the 2000, and (b) had depth data available in the 1930s.

	area < 0.20 m MSL (ha)	area >= 0.20 m MSL (ha)
1930s	200	1
1970s	43	139
2000s	16	185

Table 2. Tidal depth optima of water plants in the western Wadden Sea, and in Balgzand in particular, on the basis of a GIS-analysis of water plant maps and tidal depth maps.

Macrophyte	Depth optimum in cm MSL	Depth optimum in cm LT
Eelgrass Waddenzee 1931, by boat[1]	-100	-40
Eelgrass Balgzand 1931, by boat[1]	-70	-20
Eelgrass Balgzand 1931 location A[2]	-15 to +14	
Eelgrass Balgzand 1931 location B [2]	-50	
Eelgrass Balgzand 1972[3]	-25 to -5	
Dwarf eelgrass Balgzand 1972[3]	-5 and +20	
Widgeon grass (van't Veer, this study)	-15 to +54	

[1]Vegetation map of Reigersman et al. 1939
[2]Vegetation map of Harmsen 1936
[3]Vegetation map of Polderman & den Hartog 1975

Table 3. Average high tide (HT) and low tide (LT) level in the Balgzand area and in the seagrass beds in the Wadden Sea in 1931 (based on data of Klok & Schalkers 1980 and the seagrass bed map of Reigersman et al. 1939.

	m LT	m HT
Balgzand	-0.50	0.40
Wadden Sea seagrass beds 1931	-0.60	0.40

The settlement and expansion of widgeon grass in recent years may be explained by the decreased tidal depth following sedimentation (table 1); also in Chesapeake Bay and in the Baltic Sea, widgeon grass grows generally shallower than eelgrass (Orth & Moore 1988; Batiuk et al. 1992, Boström & Bonsdorff 2000, Moore et al. 2000). Obviously, the correlation is no indication for causality. The invasion of widgeon grass may indicate a lowered salinity, as this species has a lower salinity optimum than eelgrass (Verhoeven 1979, van Katwijk et al. 1999, Moore et al. 2000, La Peyre 2003). In the 1930's, in the Wadden Sea and Zuiderzee, the salinity range of eelgrass was 10-30 PSU (comparison seagrass maps of Oudemans et al. 1870, Reigersman 1939 with salinity data van der Hoeven 1982). At present, at the Balgzand the salinity drops frequently to 10-15 psu and occasionally as low as 5 psu), as appeared from a continuous monitoring program during 2005. The salinity drops were related to the discharges from Lake IJssel in combination with easterly winds (van Reen 2005). There are no indications that the discharge regime has changed during the last decades, though (van Reen 2005, www.waterbase.nl).

Dynamics in present natural populations in the Dutch Wadden Sea.

Since mid-1990s, four seagrass beds in the Dutch Wadden Sea have been monitored on a yearly basis (e.g. Groeneweg 2004b, Erftemeijer 2005, Fig. 1) by the Department of Public Works within the framework of the biological monitoring program. One of these beds, the eelgrass bed at Terschelling Harbour, had disappeared in 2003 (see also Fig. 4). A new bed has appeared in the Ems estuary, across a channel, 4 km west of the eelgrass population of 'Hond/Paap'. This area, called "Voolhok" is an area with high sedimentation rates. The area probably receives seed from the Hond/Paap beds since long, but only recently, the tidal depths have decreased sufficiently to provide a suitable habitat for germination and bed development. The bed was discovered in 2003 and was not present in 1999. Apart from the beds mentioned above, there are no significant seagrass occurrences in the Dutch Wadden Sea, except the small transplants of eelgrass and dwarf eelgrass at Balgzand, mentioned above.

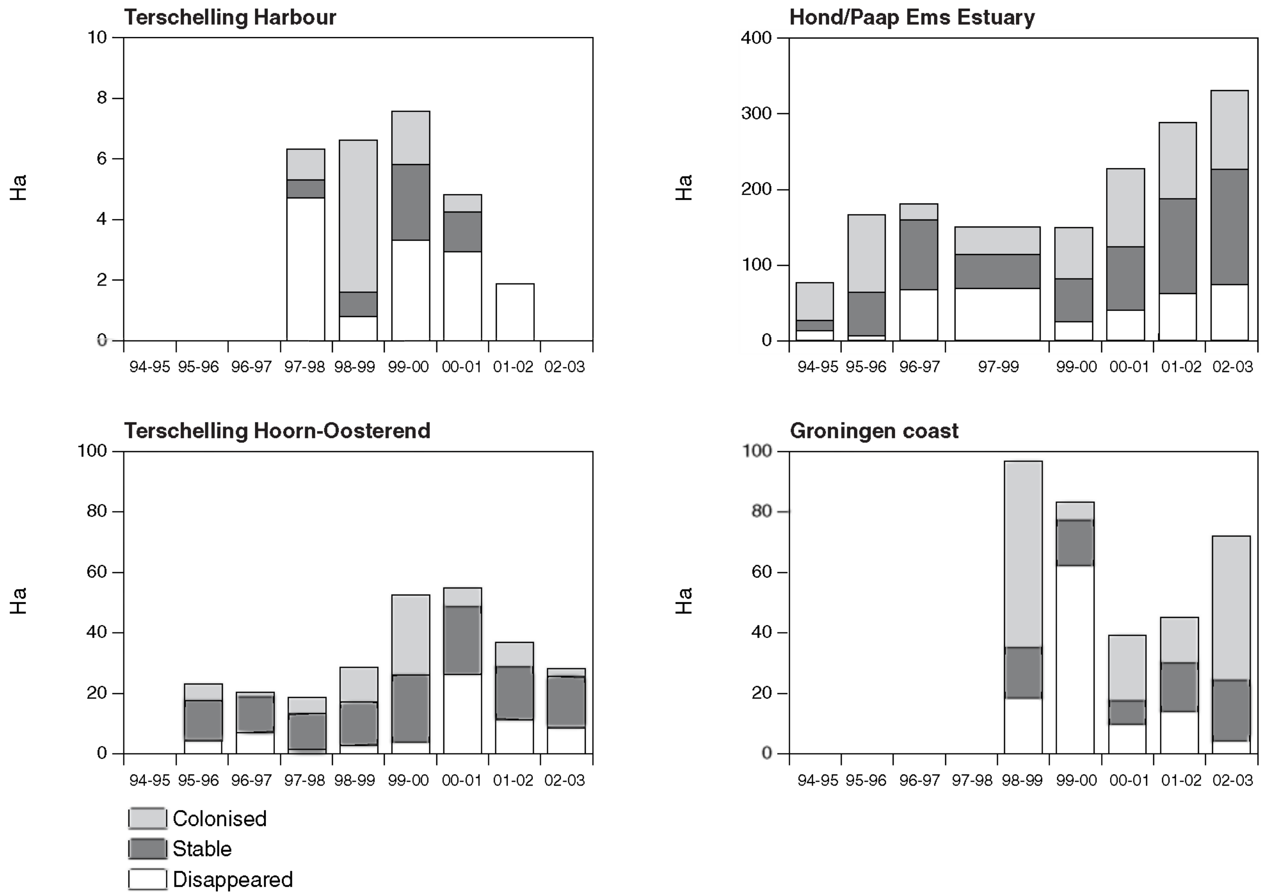

Figure 4. Dynamics of four seagrass beds in the Dutch Wadden Sea. Area of seagrass beds with 'colonised': area that is newly colonised in comparison to the preceding year, 'stable': area that was also vegetated in the preceding year, and 'disappeared': the area that was vegetated in the preceding year but not in the present year

The dynamics of the four seagrass beds in the Dutch Wadden Sea were analysed, using the monitoring data provided by the Ministry of Transport, Public Works and Water Management. Data of the following years were available and have been analysed: Terschelling Hoorn-Oosterend: 1995-2003; Groningen coast: 1998-2003; Terschelling harbour: 1998-2002; Hond/Paap in the Ems estuary: 1994-2003 with 1998 missing; we analysed 1999 data in comparison to 1997 data instead. Inaccuracies in monitoring can rise from the timing of the aerial and ground surveys, the spatial resolution of map data, the consistency in interpretation accuracy of aerial photographs and, for the category 0-5% cover that is hardly visible on aerial photographs, also the limited chance of detection in ground truthing (Frederiksen et al. 2004, Erftemeijer 2005, D. de Jong, pers. comm.)

Using GIS-analysis, we calculated the differences in surface area between two subsequent years, and made a distinction between newly *colonised* areas (areas that were not covered by seagrass in the preceding year), *stable* areas (that had seagrass cover in both years), and areas where seagrass had *disappeared* (local extinction; Fig. 4). The average percentage 'colonised', versus percentage 'stable', was relatively constant per population (no large standard errors of the mean, Fig. 5).

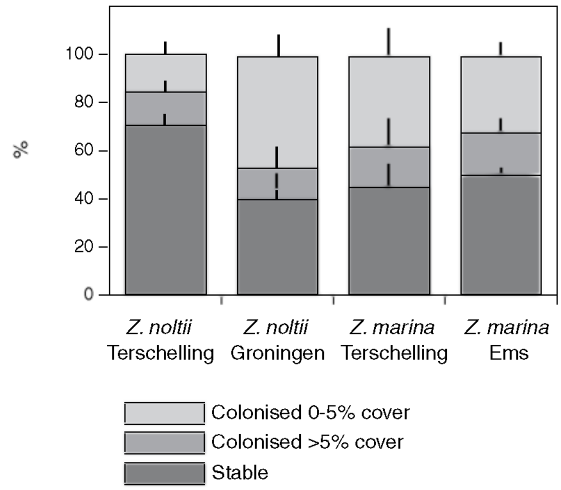

Figure 5. Percentage of the seagrass area that was newly colonised versus the area that was already covered by seagrass in the preceding year in the four seagrass localities present in the Dutch Wadden Sea. Newly colonised areas are subdivided in <5% and >5% seagrass cover.

In three out of four populations the newly colonised area was between 50 and 60% of the total population. The 'colonised' areas mainly have a cover of less than 5%. Only the dwarf eelgrass population of

Terschelling near Hoorn and Oosterend was less dynamic: at average only 30% of a seagrass area in a given year was (re-) colonised and the percentage 'stable' area (i.e. that was also seagrass-covered in the preceding year) was 70% at average. As this population shows no net losses or increases (Erftemeijer 2005), the yearly extinction in the covered area is also about 30%, which can also been seen in Fig. 4. The low extinction percentage may have been due to the compact, stabile sediments at this location (drown salt marshes) in combination with the predominantly perennial strategy of dwarf eelgrass. The low (re-) colonisation percentage indicates that the number of suitable areas in the vicinity is limited.

The high (re-) colonisation area in most seagrass beds of 50-60% yearly, means that if only the existing beds are protected, one would potentially loose 50-60% of the population in the subsequent year. The risk is particularly high in winter and spring, when the new colonisations are not yet visible. Secondly, in summer when new monitoring results are not yet present and available, the risk of overlooking a new colonisation is present when the beds are sparsely covered, i.e. <5%. At average the area with risk of overlooking was calculated to be 30-50% of the seagrass covered area (except for the Hoorn/Oosterend dwarf eelgrass population: 15%; Fig. 5). Then, in summer, a new monitoring is performed and seagrass area (= area of protection) is adjusted to the new situation. When monitoring is not performed on a yearly basis, the risk of losses increases further. This follows from the situation that the protected area will be partly un-vegetated, the unprotected area will be partly vegetated as a consequence of the yearly bed dynamics.

Notably, comparison of historic maps of 1869 and 1931 reveals that also the subtidal, perennial form of seagrass showed large dynamics: 75% of the seagrass beds present in 1931 were a new colonisation compared to 1869, whereas 25% had remained at, or re-vegetated the same location during these 72 years. 55% of the vegetation present in 1869 had disappeared in 1931 (the seeming contradictions in these percentages are due to an increase in the total seagrass cover during the period 1869 and 1931).

Transplantations of eelgrass and dwarf eelgrass at Balgzand, 1993-2004

As part of a large reintroduction programme (van Katwijk et al. 2000, van Katwijk 2003, Bos et al. 2005, Bos & van Katwijk subm.), seagrass transplantations have been carried out in 1993, 1998, 2003 and 2004. In 1993 both eelgrass and dwarf eelgrass were introduced. Dwarf eelgrass transplantations (methods: 1x1 m, 100 plants, planting date May 19th 1993, planting depths between MSL –0.4 and + 0.3 m; survival in 1994 reported between MSL –0.1 and + 0.15 m, Hermus 1995) appeared to have been successful, as they have been and are still spreading since (Fig. 6), though all colonisations are 1-2 m in diameter,

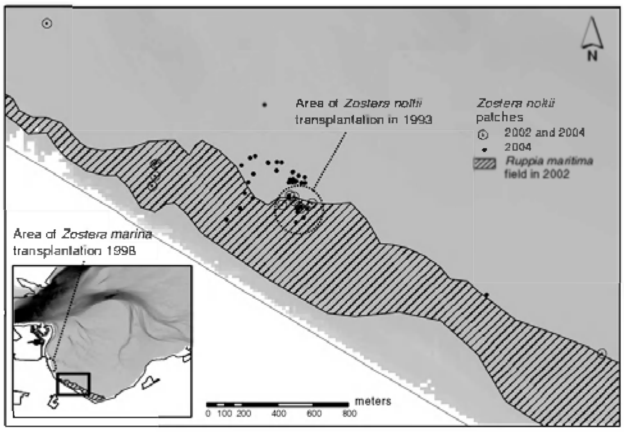

Figure 6. Dwarf eelgrass in 2002 and 2004, transplanted in 1993 at the encircled location; Inserted: location of eelgrass transplantation in 1998.

and do not form beds, yet. In 1993, eelgrass transplantations were successful only during the first growing season and did not survive through the winter, neither by surviving plants, nor through recruitment by seed (van Katwijk & Hermus 2000). Transplantations at the same location in 2003 gave similar results (Bos & van Katwijk 2005). In December 1998, seed bearing shoots (circa 5 kg wet weight) were deposited at another location within the Balgzand area (Fig. 6, details of the area see van Katwijk & Wijgergangs 2004). This transplantation was successful. However, the numbers of plants are highly variable, making this transplantation vulnerable to extinction (Table 4).

Table 4. Development of a transplantion of eelgrass plants at Balgzand, resulting from a donation of seed bearing shoots in December 1998.

year	number of plants	ha
1999	Ca. 100	
2000	Ca. 300	
2001	Ca. 200	
2002	13	
2003	Ca. 800	5.3
2004	50	

Conclusions and recommendations

From monitoring data covering 75 years, we could relate the sedimentation at Balgzand (decreased tidal depth) with a sequence of water plant species dominance in the area (eelgrass dominance, followed by dwarf eelgrass dominance, followed by widgeon grass dominance, Table 1 and 2, Fig. 3).

This temporal relationship corresponds to known spatial relationships (zonation): also in Chesapeake Bay and in the Baltic Sea (Orth & Moore 1988; Batiuk et al. 1992; Boström & Bonsdorff 2000, Moore et al., 2000). *Ruppia* grows shallower than *Zostera*, and dwarf eelgrass is known to occur shallower than eelgrass in the rest of the Wadden Sea, but also in the UK and Brittany, France (Harmsen 1936, Wohlenberg 1935, den Hartog & Polderman 1975, personal observation), with exception of an eelgrass zone with a wintergreen perennial strategy, that occasionally can be encountered in a zone above the dwarf eelgrass zone (van Katwijk et al. 1998). This consistency between the temporal relationship and the zonation patterns suggests that this relationship may be causal. In other words, the invasion of widgeon grass may have been caused by the sedimentation in the Balgzand area. However, based on the depth profiles, one would have expected the invasion sooner: already in the 1970s, the area had silted up considerably (Table 1).

Additionally, other explanations for the observed sequence of macrophyte cover over 75 years are possible. For example, it is known that widgeon grass has a much lower salinity optimum than *Zostera* species (e.g. Verhoeven 1979, Moore et al. 2000). Low salinities have been measured at the Balgzand area (van Reen 2005), offering a possible explanation of the presence of *Ruppia maritima*. However, also in this case an invasion would have been expected earlier as the discharges have not increased or decreased during the last 30 years (www.waterbase.nl). Distributional impairments could have caused the delayed establishment: seeds can travel by birds (Figuerola & Green 2002, Figuerola et al. 2002), but only occasionally this may result in a successful establishment (Clausen et al. 2002). Another means of transportation would be detached shoots bearing seeds (Cho & Poirrier 2005), which can probably travel over large distances, as was found for eelgrass (Harwell & Orth 2002, Reusch 2002, Erftemeijer et al. subm.). Once established, that plants can expand rapidly (Silberhorn et al. 1996, Cho & Poirrier 2005). One may also tentatively speculate that the low general environmental quality during the 1970s and 1980s (high levels of turbidity, eutrophication, heavy metals, toxicants, Marijnissen et al. 2001, de Jonge & de Jong 2002, van Beusekom & de Jonge 2002), may have prevented an earlier establishment of *Ruppia*.

Our GIS-study shows that seagrass bed dynamics are high. Between 1869 and 1931, only 30% of the subtidal beds of the robust type of eelgrass had remained at the same location, whereas 70% had 'moved'. Additionally, the population had expanded with a 25% increase in surface area (note that these are net values: we do not know the dynamics in the intermediate years). Present day seagrass beds, composed of the flexible type of eelgrass and dwarf eelgrass, show yearly shifts of 50-60%. Below, we will elaborate the implications of these dynamics to protection measures.

The importance of regulating shellfish fisheries to effectively protect seagrass beds was shown by de Jonge & de Jong (1992), van Katwijk (2003) and Essink et al. (2003). At the Groningen coast, Essink and co-workers recently recorded the loss of a substantial part of the dwarf eelgrass population following shellfisheries activities. They recommend a buffer zone of 400 m for the Groningen coast. Our study of the observed year-to-year dynamics of the Dutch Wadden Sea seagrass populations indeed urge the need for protection of a larger area than only the present seagrass bed. By doing the latter, one may potentially loose more than 50% of the bed each year (Fig. 5). We recommend that the buffer zone should be established on the basis of the area surrounding the beds that can be considered as suitable for seagrass. The latter can be accomplished by using the habitat suitability model (de Jong et al. 2005, Bos et al. 2005), and on-site expert judgement. Additionally, long-term trend analyses of the bed dynamics (e.g. Erftemeijer 2005, www.zeegras.nl) could help to establish the potentially suitable areas surrounding seagrass beds.

To allow for a larger scale expansion of existing seagrass populations, protection of high potential seagrass areas remote of existing beds is recommended. The recent establishment of a bed more than 4 km remote from an existing bed proves that seagrass is capable to establish outside the direct margins of existing beds. To assign high potential areas, the habitat suitability model for seagrass in the Dutch Wadden Sea can be used (de Jong et al. 2005, Bos et al. 2005). Within the areas appointed by the model, a further refinement should be made at the site, to account for local circumstances. Both the establishment of large buffer zones surrounding seagrass beds and the establishment of protected areas at high potential areas are recommended to be incorporated in EU-regulations and in Wadden Sea management plans.

From the results of transplantations at Balgzand in 1993 (dwarf eelgrass) and 1998 (eelgrass), and from the GIS-analyses in this study, we can conclude that both seagrass transplantations and beds are highly dynamic. A dynamic population strategy is obviously the best strategy in a dynamic environment such as the Wadden Sea. From this, we recommend that transplantation programmes should spread risks in space and time, which is basically what natural populations do as well.

Another recommendation that rises from the observed dynamics is to monitor the abiotic variables in the seagrass beds. Correlations between seagrass dynamics and these environmental variables will provide invaluable insight in the habitat requirements of these threatened species. Variables of interest are, for example depth, salinity and nutrient concentrations during a tidal cycle and over a season (van Katwijk et al. 2000). Additionally, to get insight in the causes of local disappearances that occur in natural beds (Fig. 5) as well as in transplantations (Table 2, Bos et al. 2004, Bos & van Katwijk 2005), continuous visual monitoring is recommended. In monitoring the transplantations, very sudden disappearances during the growing season were detected. When did these plants disappear exactly? After an abundant visit of foraging birds, or after a period of a particular combination of wind speed and direction? Etcetera. Continuous visual monitoring, e.g. using webcams, is a technique that is presently coming into reach to efficiently provide this information.

References

Batiuk, R. A., Orth, R. J., Moore, K. A., Dennison, W. C., Stevenson, J. C., Staver, L. W., Carter, V., Rybicki, N. B., Hickman, R. E., Kollar, S., Bieber, S. & Heasly, P. 1992: Chesapeake Bay submerged aquatic vegetation habitat requirements and restoration targets: a technical synthesis. U.S. Environmental Protection Agency, Annapolis, Maryland.

Boley, K. E. 1988: Morphodynamische Analyse der Wattsüdseite Hallig Hooge. Geographisches Institut der Justus Liebig Universität Giessen, Giessen.

Bos, A. R., Hermus, D. C. R. & van Katwijk, M. M. 2004: Herintroductie van Zostera marina in de westelijke Waddenzee (2002-2006). Resultatenrapportage 2003. Report Dep. of Environmental Studies, University of Nijmegen.

Bos, A. R., Hermus & van Katwijk, M.M. 2005: Herintroductie van groot zeegras (Zostera marina) in de westelijke Waddenzee (2002-2005). Report Dep. of Environmental Science, Radboud University Nijmegen, The Netherlands.

Bos, A. R., Dankers, N., Groeneweg, A. H., Hermus, D. C. R., Jager, Z., de Jong, D. J., Smit, T., de Vlas, J., van Wieringen, M. & van Katwijk, M. M. 2005: Eelgrass (Zostera marina L.) in the western Wadden Sea. Monitoring, potential habitats, transplantations and communication. Proceedings Dunes & Estuaries, 19-23 September 2005, Koksijde. VLIZ Special Publication 19, Koksijde, Belgium.

Bos, A. R. & van Katwijk, M.M. Planting density, hydrodynamic exposure and mussel beds affecting survival of transplanted intertidal eelgrass. Submitted Marine Ecology Progress Series.

Boström, C. & Bonsdorff, E. 2000: Zoobenthic community establishment and habitat complexity - the importance of seagrass shoot-density, morphology and physical disturbance for faunal recruitment. Marine Ecology Progress Series 205, 123-138.

Cho, H. J. & Poirrier, M. A. 2005: Seasonal growth and reproduction of Ruppia maritima L. s.l. in Lake Pontchartrain, Louisiana, USA. Aquatic Botany 81, 37-49.

Clausen, P., Nolet, B. A., Fox, A. D. & Klaassen, M. 2002: Long-distance endozoochorous dispersal of submerged macrophyte seeds by migratory waterbirds in northern Europe - a critical review of possibilities and limitations. Acta Oecologica International Journal of Ecology 23, 191-203.

de Jong, D. J., Brinkman, A. G. & van Katwijk, M. M, 2005: Kansenkaart zeegras Waddenzee. Potentiële groeimogelijkheden voor zeegras in de Waddenzee. Report RIKZ/2005.013, Rijkswaterstaat, Middelburg, the Netherlands.

de Jonge, V. N. & de Jong, D. J. 1992: Role of tide, light and fisheries in the decline of Zostera marina L. in the Dutch Wadden Sea. Netherlands Institute for Sea Research Publication Series 20, 161-176.

de Jonge, V. N. & Ruiter, J. F. 1996: How subtidal were the 'subtidal beds' of Zostera marina L. before the occurrence of the wasting disease in the early 1930's? Netherlands Journal of Aquatic Ecology 30, 99-106.

de Jonge, V. N., and D. J. de Jong. 2002. 'Global change' impact of inter-annual variation in water discharge as a driving factor to dredging and spoil disposal in the river Rhine system and of turbidity in the Wadden Sea. Estuarine Coastal And Shelf Science 55:969-991.

den Hartog, C. & Polderman, P. J. G. 1975: Changes in the seagrass populations of the Dutch Waddenzee. Aquatic Botany 1, 141-147.

den Hartog, C. 1996: Sudden declines of seagrass beds: "wasting disease" and other disasters. In: Seagrass Biology: Proceedings of an International Workshop. Rottnest Island, Western Australia, 25-29 January 1996 (Kuo, J., Phillips, R. C., Walker, D. I. & Kirkman, H., eds). University of Western Australia, Nedlands, pp. 307-314.

Erftemeijer, P. L. A. 2005: Trendanalyse van zeegrasverspreiding in de Nederlandse Waddenzee 1988-2003. Report Z3880, Delft Hydraulics, The Netherlands.

Erftemeijer, P.L.A., J.K.L. van Beek, C.A. Ochieng, H.J. Los, Z. Jager and D.J. de Jong, submitted: Eelgrass seed dispersal in the Dutch Wadden Sea: a model approach. Submitted Marine Ecology Progress Series.

Essink, K., de Vlas, J., Nijssen, R. & Poot, G. J. M. 2003: Heeft mechanische kokkelvisserij invloed gehad op de ontwikkeling van zeegras in de Nederlandse Waddenzee? Rapport RIKZ/2002.026, Haren, The Netherlands.

Figuerola, J., Green, A. J., & Santamaria, L. 2002: Comparative dispersal effectiveness of wigeon-grass seeds by waterfowl wintering in south-west Spain: quantitative and qualitative aspects. Journal of Ecology 90, 989-1001.

Figuerola, J. & Green, A. J. 2002: Dispersal of aquatic organisms by waterbirds: a review of past research and priorities for future studies. Freshwater Biology 47, 483-494.

Frederiksen, M., Krause, J. D., Holmer, M. & Laursen, J. S. 2004: Long-term changes in area distribution of eelgrass (Zostera marina) in Danish coastal waters. Aquatic Botany 78, 167-181.

Giesen, W. B. J. T., van Katwijk, M. M. & den Hartog, C. 1990a: Eelgrass condition and turbidity in the Dutch Wadden Sea. Aquatic Botany 37, 71-85.

Giesen, W. B. J. T., van Katwijk, M. M. & den Hartog, C. 1990b: Temperature, salinity, insolation and wasting disease of eelgrass (Zostera marina L.) in the Dutch Wadden Sea in the 1930's. Netherlands Journal of Sea Research 25, 395-404.

Groeneweg, A. H. 2004a: Rapportage zaadplanten kartering Balgzand & Breehorn 2004. AGI/1104/GAE003. Rijkswaterstaat, Adviesdienst Geo-informatie en ICT, Delft, the Netherlands.

Groeneweg, A. H. 2004b: Verslag macrofytobenthos & zeegraskartering in Oosterschelde en Waddenzee 2003, deels op basis van false colour-luchtfoto's schaal 1:10.000. Rijkswaterstaat, Adviesdienst Geo-informatie en ICT, Delft, the Netherlands.

Harmsen, G. W. 1936: Systematische Beobachtungen der Nordwest-Europäischen Seegrasformen. Nederlands Kruidkundig Archief 46, 852-877.

Harwell, M. C., and R. J. Orth. 2002: Long-distance dispersal potential in a marine macrophyte. Ecology 83, 3319-3330.

Hermus, D. C. R. 1995: Herintroduktie van zeegras in de Waddenzee. Het verloop van de beplantingen in 1992-1994 & zaadexperimenten. Department of Aquatic Ecology and Environmental Biology, University of Nijmegen.

Klok, B. & Schalkers, K. M. 1980: De veranderingen in de Waddenzee ten gevolge van de afsluiting van de Zuiderzee. Rijkswaterstaat Dir. waterhuishouding en waterbeweging., Studiedienst Hoorn.

La Peyre, M. K. & Rowe, S. 2003: Effects of salinity changes on growth of Ruppia maritima L. Aquatic Botany 77, 235-241.

Marijnissen, S., Frederiks, B., Smit, T. & van de Ven, K. 2001: Emissies naar de Waddenzee 1985-1999. Report RIKZ/2001.048, Rijkswaterstaat, Haren, The Netherlands.

Moore, K. A., Wilcox, D. J. & Orth, R. J. 2000: Analysis of the abundance of submersed aquatic vegetation communities in the Chesapeake Bay. Estuaries 23, 115-127.

Orth, R. J. & Moore, K. A. 1988: Distribution of Zostera marina L. and Ruppia maritima L. sensu lato along depth gradients in the lower Chesapeake Bay, U.S.A. Aquatic Botany 32, 291-305.

Oudemans, C. A. J. A., Conrad, J. F. W., Maats, P. & Bouricius, L. J. 1870: Verslag der Staatscommissie inzake de wiermaayerij. In: Verslag aan den Koning over de Openbare Werken in het Jaar 1869 Van Weelden en Mingelen, Den Haag, pp. 199-231.

Polderman, P. J. G. & den Hartog, C. 1975: De zeegrassen in de Waddenzee. K. Ned.-Natuurh.Veren.Wet.Meded. 107, 1-32.

Reigersman, C. J. A., Houben, G. F. H. & Havinga, B. 1939: Rapport omtrent den invloed van de wierziekte op den achteruitgang van de wierbedrijven, met Bijlagen. Provinciale Waterstaat in Noord-Holland, Haarlem.

Reusch, T. B. H. 2002: Microsatellites reveal high population connectivity in eelgrass (Zostera marina) in two contrasting coastal areas. Limnology and Oceanography 47, 78-85.

Silberhorn, G. M., Dewing, S. & Mason, P. A. 1996: Production of reproductive shoots, vegetative shoots, and seeds in populations of Ruppia maritima L from the Chesapeake Bay, Virginia. Wetlands 16, 232-239.

van Beusekom, J. E. E. & de Jonge, V. N. 2002: Long-term changes in Wadden Sea nutrient cycles: importance of organic matter import from the North Sea. Hydrobiologia 475, 185-194.

van der Hoeven, P. C. T. 1982: Watertemperatuur en Zoutgehaltewaarnemingen van het Rijksinstituut voor Visserij Onderzoek (RIVO): 1860 - 1981. Scientific report W.R. 82-8. Koninklijk Nederlands Metereologisch Instituut, De Bilt.

van Goor, A. C. J. 1920: Das Wachstum der Zostera marina L. Ber.deutschen Bot.Ges 38, 187-192.

van Katwijk, M. M., Schmitz, G. H. W., Hanssen, L. S. A. M. & den Hartog, C. 1998: Suitability of Zostera marina populations for transplantation to the Wadden Sea as determined by a mesocosm shading experiment. Aquatic Botany 60, 283-305.

van Katwijk, M. M., Schmitz, G. H. W., Gasseling, A. M. & van Avesaath, P. H. 1999: The effects of salinity and nutrient load and their interaction on Zostera marina L. Marine Ecology Progress Series 190, 155-165.

van Katwijk, M. M. & Hermus, D. C. R. 2000: Effects of water dynamics on Zostera marina: transplantation experiments in the intertidal Dutch Wadden Sea. Marine Ecology Progress Series 208, 107-118.

van Katwijk, M. M., Hermus, D. C. R., de Jong, D. J., Asmus, R. M. & de Jonge, V. N. 2000: Habitat suitability of the Wadden Sea for restoration of Zostera marina beds. Helgoland Marine Research 54, 117-128.

van Katwijk, M. M. 2003: Reintroduction of eelgrass (Zostera marina L.) in the Dutch Wadden Sea; a research overview and management vision. In: Challenges to the Wadden Sea. Proceedings of the 10th International Scientific Wadden Sea Symposium, Groningen 2000. (Wolff, W. J., Essink, K., Kellermann, A. & van Leeuwe, M., eds). Ministry of Agriculture Nature Management and Fisheries / University of Groningen, Dept. of Marine Biology, Den Haag, pp. 173-197.

van Katwijk, M. M. & Wijgergangs, L. J. M. 2004: Effects of locally varying exposure, sediment type and low-tide water cover on Zostera marina recruitment from seed. Aquatic Botany 80, 1-12.

van Reen, M. J. 2005: Saliniteit op het Balgzand. Analyse van saliniteit in relatie met zoetwaterdebieten op de westelijke Waddenzee, inclusief historische beschouwing. Report A1550, Alkyon, Emmeloord, The Netherlands.

Verhoeven, J. T. A. 1979: Ecology of Ruppia-dominated communities in western Europe. 1. Distribution of Ruppia representatives in relation to their autecology. Aquatic Botany 6, 197-268.

Wohlenberg, E. 1935: Beobachtungen über das Seegrass, Zostera marina L., und seine Erkrankung im nordfriesischen Wattenmeer. Beiträge zur Heimatforschung im Schleswig-Holstein, Hamburg und Lübeck 2, 1-19.

Long-term changes in intertidal macrozoobenthos; the wax of polychaetes and wane of bivalves?

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Essink, K.*, Damm-Böcker, S., Dekker, R., Kleef, H., Madsen, P.B. & Ullerup, N. 2006: Long-term changes in intertidal macrozoobenthos; the wax of polychaetes and wane of bivalves? In: Monitoring and Assessment in the Wadden Sea. Proceedings from the 11. Scientific Wadden Sea Symposium, Esbjerg, Denmark, 4.-8. April, 2005 (Laursen, K. Ed.) NERI Technical Report No. 573, pp. 99-105.

At a number of fixed locations in the Dutch, German and Danish Wadden Sea intertidal macrozoobenthos is monitored in the framework of the Trilateral Monitoring and Assessment Programme (TMAP). At the 9th International Scientific Wadden Sea Symposium (Norderney 1996), the results of this long-term trend monitoring programme were used to answer the question whether trends in biomass in different parts of the Wadden Sea were governed by differences in nutrient loads. At that time, that specific question could not unequivocally be answered. An obvious trend, however, was shown of increasing biomass values of polychaetes, whereas bivalve biomass showed strong fluctuations mainly governed by the severity of winter conditions.

In this contribution, new data on the development of bivalve and polychaete populations still show the same picture of 1) fluctuating bivalve biomass and 2) an increase of polychaetes. Individual polychaete species, however, sometimes show different trends, even at a scale of less than one kilometre. This suggests that sediment composition and associated fauna play a yet not understood role in the development of these polychaetes.

Key words: Arenicola marina, biomass, Heteromastus filiformis, monitoring, Macoma balthica, Nereis diversicolor, Scoloplos armiger, Wadden Sea

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Introduction

In a previous paper, presented at the 9th International Scientific Wadden Sea Symposium, November 1996, we presented long-term data on biomass of intertidal macrozoobenthic biomass and addressed the question whether biomass of these species was governed by nutrient loads (Essink et al. 1998). On that occasion we compared data sets from different parts of the Wadden Sea and tried to relate the biomass development with changes in riverine nutrient discharge, nutrient concentrations in the water and chlorophyll concentrations as a measure of phytoplankton biomass. The conclusions were the following:

1. the macrozoobenthic biomass showed large interannual fluctuations, which were mainly caused by bivalves.
2. these fluctuations in biomass were to a great extent synchronised by the character of winters, particularly severe winters which usually are followed by good reproduction of bivalves.
3. the total biomass of polychaetes showed a long-term increasing trend, with the exception however of the Danish Wadden Sea where no trend was discernable.

4. it was not possible to demonstrate a relationship between the increase of polychaete biomass on the one hand side and the trends of nutrient loads in the different parts of the Wadden Sea on the other.

In the present paper an update will be presented, with further data on the development of bivalves and polychaetes living at intertidal flats of the Wadden Sea.

Material and methods

In the international Wadden Sea monitoring programmes of intertidal macrozoobenthos are executed by different Danish, German and Dutch monitoring institutes, and coordinated within the Trilateral Monitoring and Assessment Program (TMAP 2000) (Fig. 1). For this study data on total macrozoobenthic biomass, and the biomass of the separate groups of bivalves and polychaetes were used.

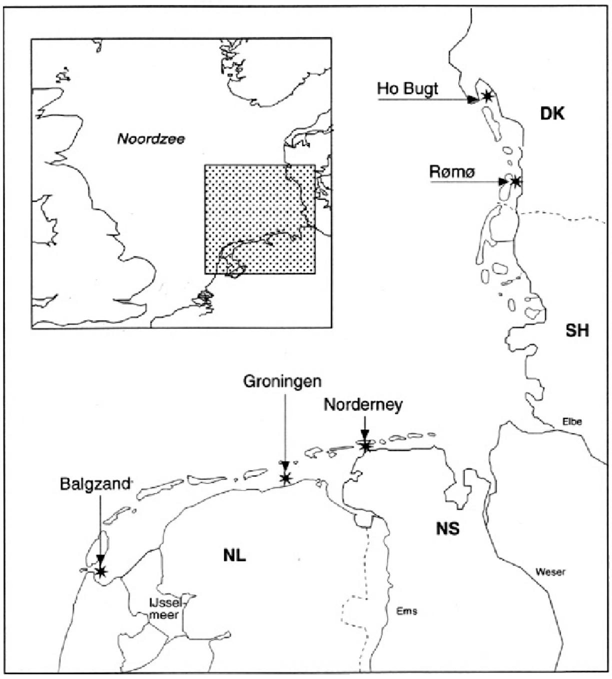

Figure 1. Map of the international Wadden Sea showing the five sub-areas where intertidal macrozoobenthos is monitored within the Trilateral Monitoring and Assessment Program (TMAP). NL: The Netherlands; NS: Niedersachsen (Lower Saxony); SH: Schleswig-Holstein; DK: Denmark.

Macrozoobenthos was monitored at fixed stations and transects, at the end of winter and in late summer/early autumn. From these data annual means were calculated as the average of winter and summer/autumn values and used as indicator of population size. Biomass was expressed in gram ash-free dry weight (AFDW) of the soft parts of the species involved.

Details regarding sampling, sorting of samples and of biomass determination are as given in Essink et al. (1998). It must be noted that for the Danish Wadden Sea 'total polychaete biomass' relates to only the major four species in the community, viz. lugworm *(Arenicola marina)*, ragworm *(Nereis diversicolor)*, *Heteromastus filiformis* and *Scoloplos armiger* (Madsen et al. 2005).

Results

Total biomass and bivalves

To illustrate the long-term development of total biomass and of bivalves data are presented from three sub-areas: western Dutch Wadden Sea (Balgzand), Lower Saxony (Norderney) and Danish Wadden Sea (Rømø area and Ho Bugt) (Fig. 2). It can be seen that the fluctuations of total biomass are virtually determined by the fluctuations in bivalve biomass. On average, bivalves constitute 40 – 60% of the total macrozoobenthic biomass.

The data sets of Balgzand and Rømø area, most clearly the autumn data, show a decreasing trend of bivalve biomass from 1998 onwards. At Norderney and Ho Bugt such a trend is not clear. At Norderney, autumn values are decreasing since 2001; at Ho Bugt the decrease started already in 1988.

Polychaetes

Polychaete biomass shows different trends in the different sub-areas of the Wadden Sea (Fig. 3). At Balgzand there is a continuously increasing biomass (from approx. 6 gram AFDW m-2 in 1980 to more than 20 gram AFDW m-2 in 1999 and 2003). A similar increase was observed at Norderney, whereas in the eastern Dutch Wadden Sea (Groningen) and in Ho Bugt no trend was apparent. In the Rømø area an apparent increase of polychaete biomass (only 4 major species determined) was followed by a steep decrease since 1999.

Single species among the polychaetes do not always show the same development (Fig. 4). The ragworm *(Nereis diversicolor)* shows increasing biomass values at Norderney and Ho Bugt, whereas at Groningen a decreasing trend is present. A different pattern, of an initial increase, followed by a decrease, was observed in the Rømø area. Different developments may occur even at small distances (less than one kilometre) as shown for Groningen in Fig. 5. The decreasing trend which is present at three fixed stations (47-0, 51-2, 54-0) with a more muddy sediment is not present at the more sandy stations 47-1 and 54-1.

The deposit-feeding polychaete *Heteromastus filiformis* shows an increasing biomass at Norderney intertidal flats, and a similar increase may be present in the Rømø area (Fig. 6). At Ho Bugt, no clear trend is visible. Again, the Groningen data show how the development of a polychaete species may be location dependent, with a decreasing trend

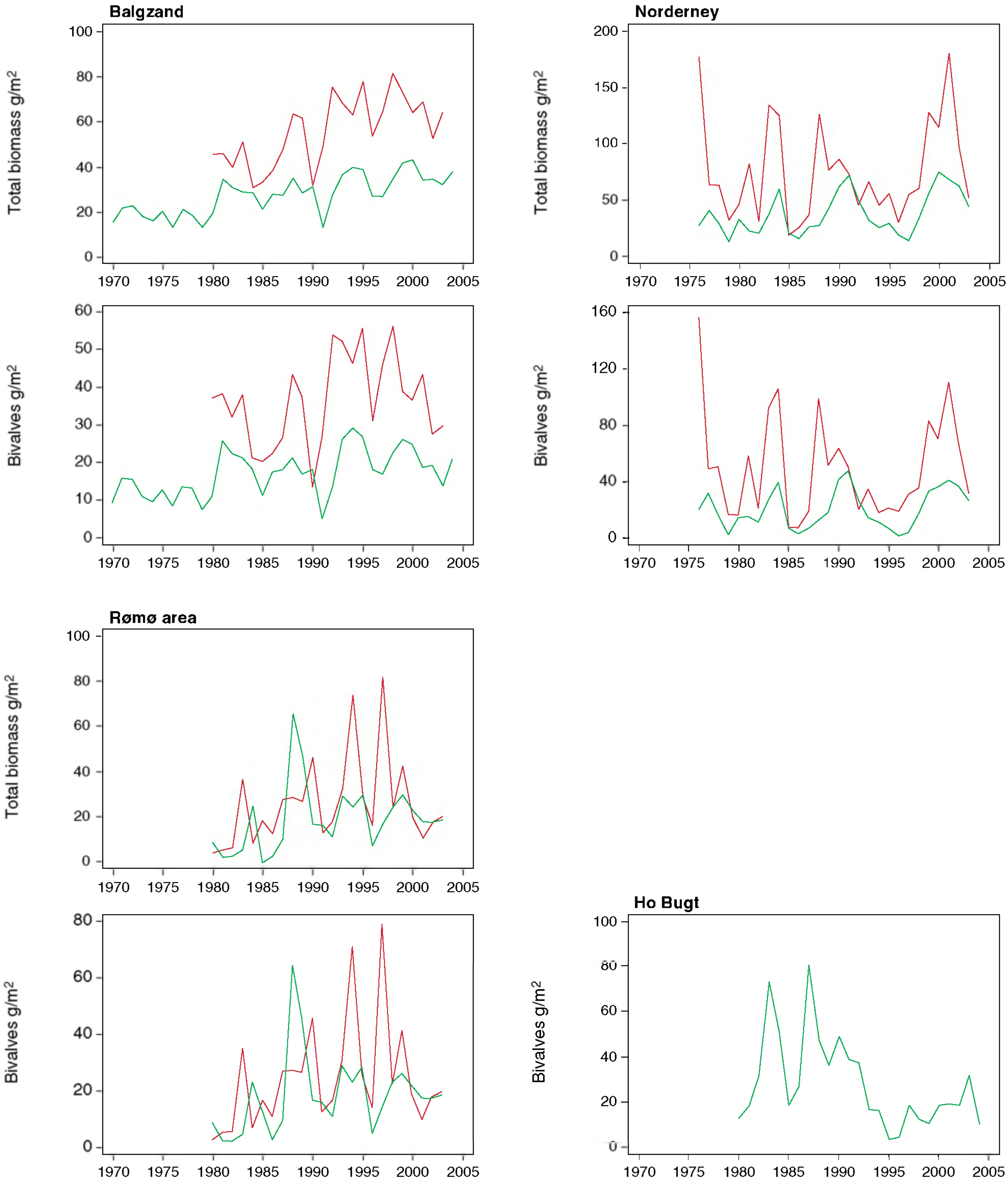

Figure 2. Biomass of total macrozoobenthos and of bivalves at intertidal flats of Balgzand, Norderney, Rømø area and Ho Bugt. Biomass: gram AFDW m-2. Red lines: autumn; black lines: spring. Note: 1) vertical axes have different scales; 2) Ho Bugt graph represents annual mean biomass.

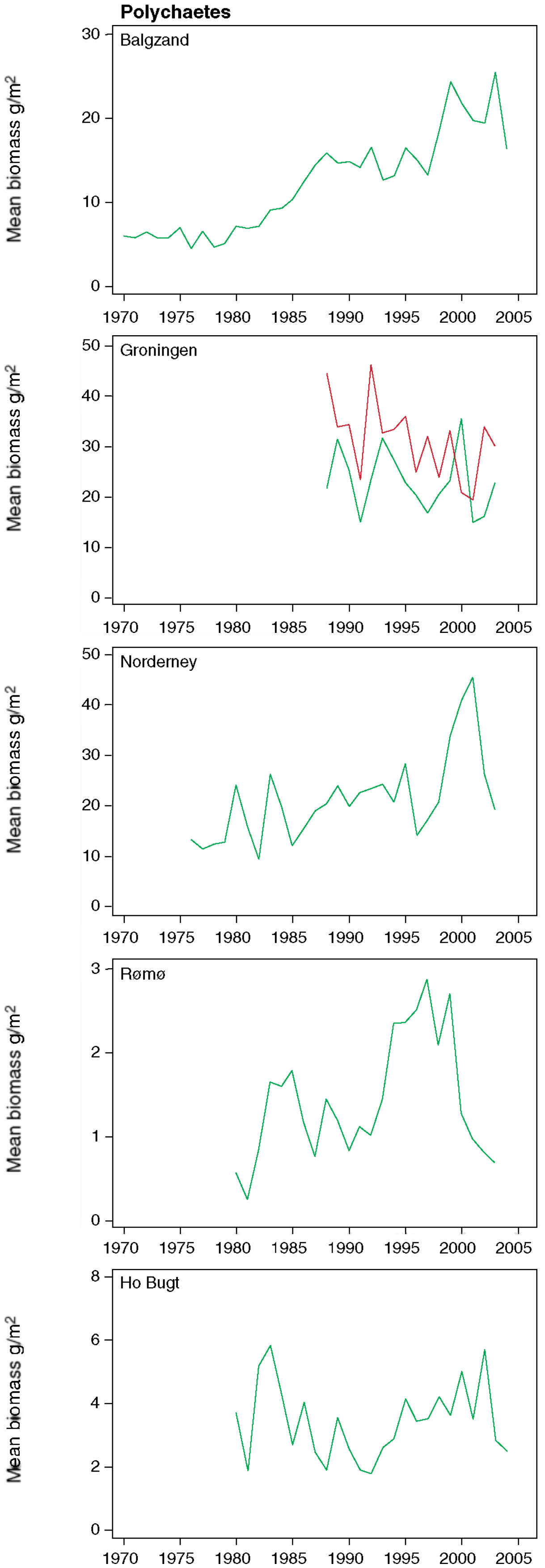

Figure 3. Annual mean biomass of polychaetes (gram AFDW m-2) at intertidal flats of Balgzand, Groningen, Norderney, Rømø area and Ho Bugt. Note: in Rømø area and Ho Bugt only four polychaete species were quantified; Groningen: black line = spring, red line = autumn.

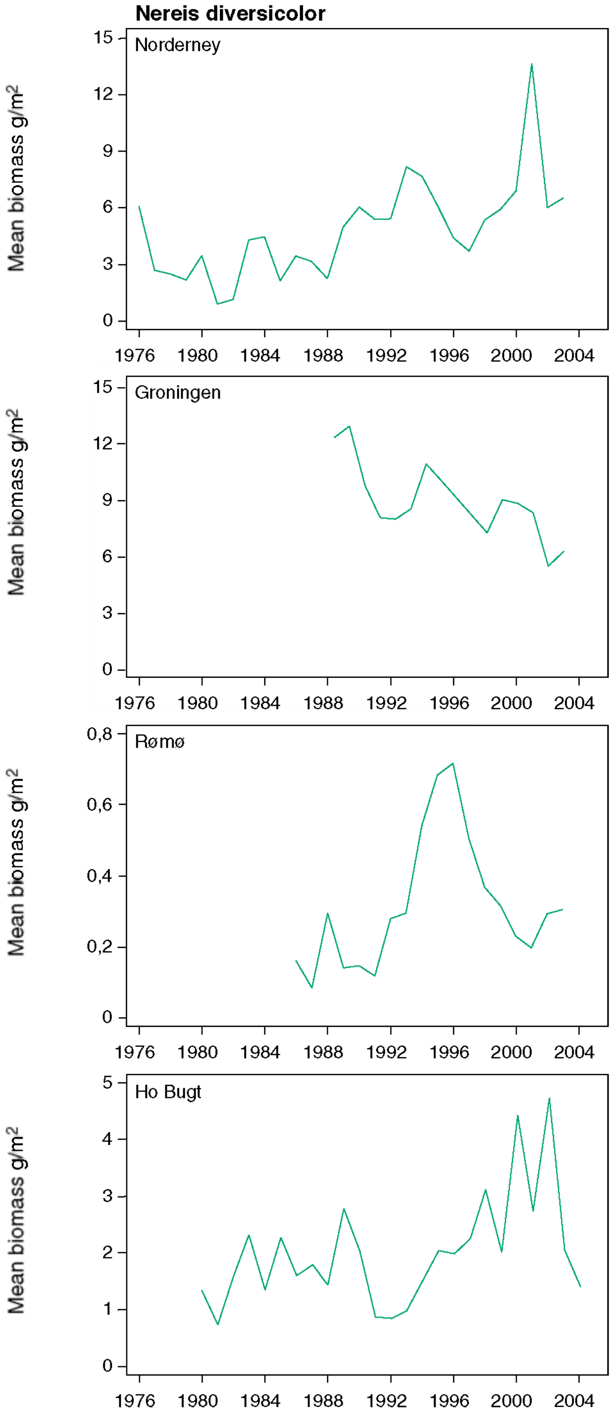

Figure 4. Development of annual mean biomass (gram AFDW m-2) of *Nereis diversicolor* at the intertidal flats of Groningen, Norderney, Rømø area and Ho Bugt. Note: different vertical scales.

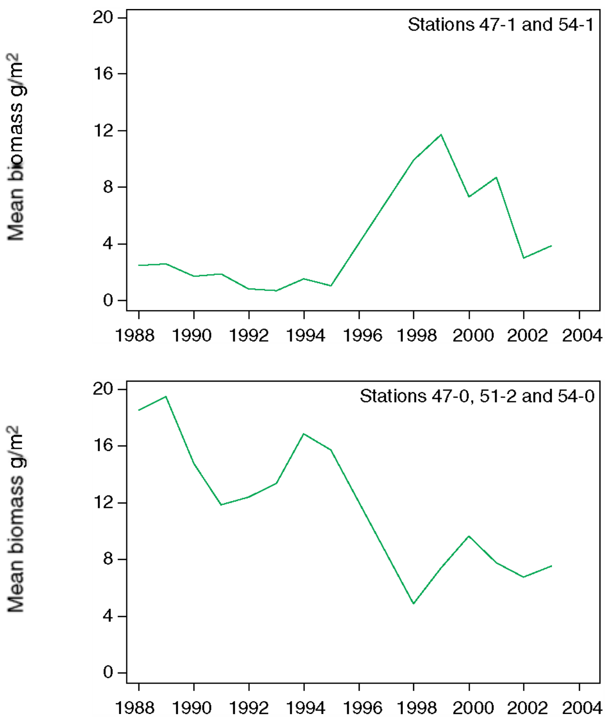

Figure 5. Different trends of annual mean biomass (gram AFDW m-2) of *Nereis diversicolor* at two sandy (top panel) and three muddy stations (lower panel) at Groningen intertidal flats.

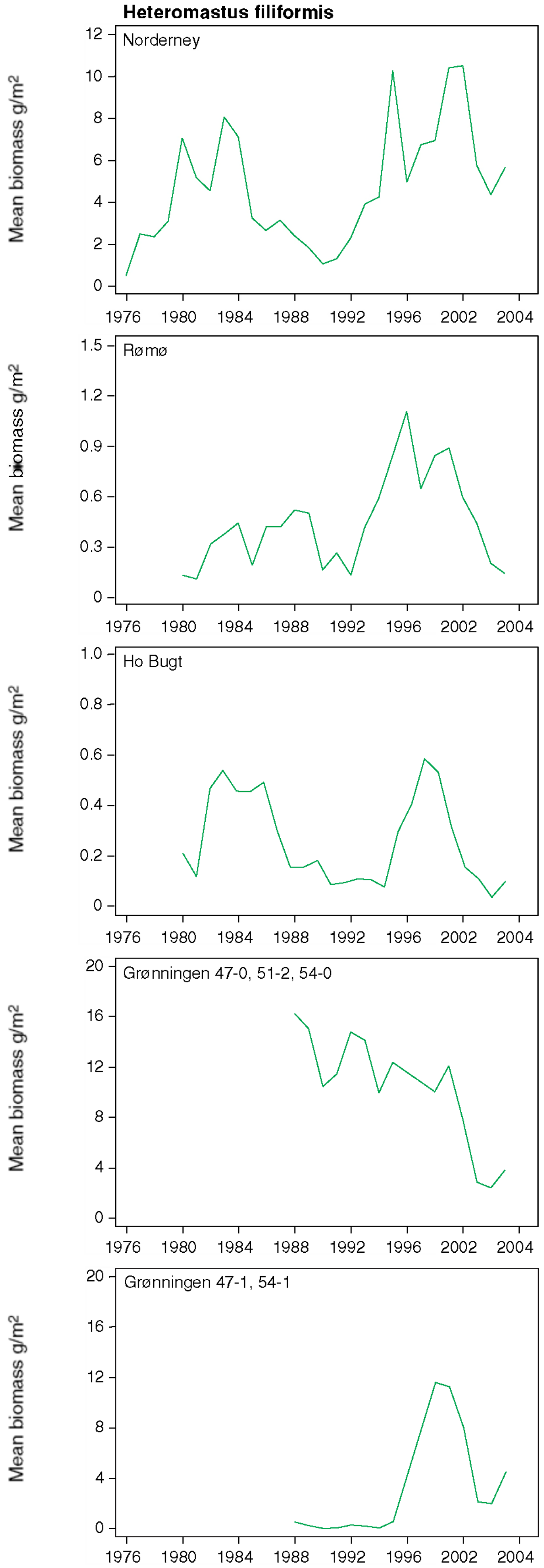

Figure 6. Development of annual mean biomass (gram AFDW m-2) of *Heteromastus filiformis* at the intertidal flats of Norderney, Rømø area, Ho Bugt and Groningen. Note: different vertical scales.

at three muddy stations and an appearance since 1995 in two other stations, which are sandy

Polychaete species may even show a quite opposite development, such as *Scoloplos armiger*. This polychaete shows a steady increase at Norderney and a decrease – after 1984 - in the Rømø area (Fig. 7). In Ho Bugt, after 1985, no clear trend is visible.

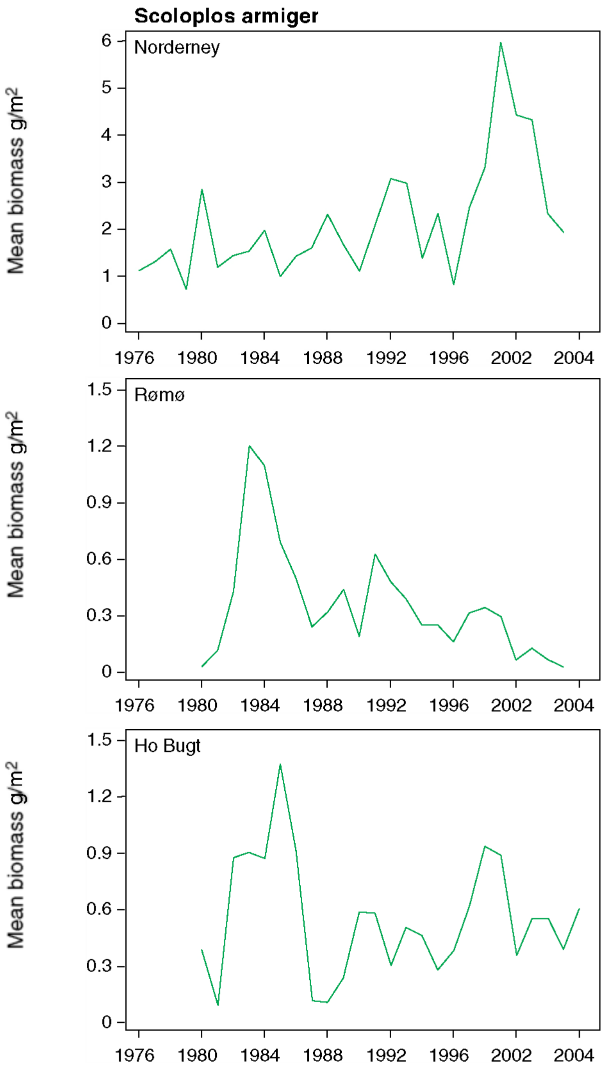

Figure 7. Development of annual mean biomass (gram AFDW m-2) of *Scoloplos armiger* at the intertidal flats of Norderney, Rømø area and Ho Bugt.

Discussion

The pattern of fluctuating bivalve populations shown earlier by Essink et al (1998) did not really change. Bivalves are largely responsible for the fluctuations of the total macrozoobenthic biomass living in intertidal flats of the Wadden Sea,

The total biomass of polychaetes showed continued increase at most sub-areas monitored. A clear relationship of this increase with eutrophication, as hypothesised by Essink et al (1998), does not seem to be present as riverine nutrient discharges into the Wadden Sea have been continuously decreasing (Van Beusekom et al. 2005; Van Beusekom 2006). However, even when assuming a total polychaete biomass in the Rømø area of twice the value of the four major species, biomass values in the northern Wadden Sea were much lower than in the southern part (Balgzand – Norderney).. Most of these polychaetous are deposit feeders, except e.g. the predator *Nephtys hombergii*. This difference in biomass may therefore still be a reflection of the different degree of eutrophication of these parts of the Wadden Sea as demonstrated by Van Beusekom et al (2005) and Van Beusekom (2006). Such a simple explanation, however, may be too easy since within a species opposite trends do occur at different localities. So, apparently different conditions are present, probably also including predator – prey relationships. Similarly, Rachor (2000) described differential development of benthic macrofauna biomass in muddy and sandy sediments in the German Bight during the period of strong eutrophication increase in the 20th century. The importance in local conditions, facilitating or limiting a response of zoobenthic biomass to changes in the trophic condition of the system were also shown by Beukema et al. (2002) for Balgzand intertidal flats.

Kröncke et al. (2001) assume that the observed increase since 1988 (until 1999) of abundance, biomass and species number in sublittoral benthic communities off the island of Norderney may be the result of a change in North Atlantic Oscillation (NAO) causing higher sea surface temperatures in late winter and early spring as well as increased primary production. Such relationships, however, have not yet been investigated with respect to intertidal benthic communities of the Wadden Sea.

The different trends within the same species on a small spatial scale as observed at Groningen intertidal flats suggests an intricate regulation of population size of these polychaetes. To unravel these details a further analysis of the data is necessary.

With respect to bivalves a decreasing trend since 1999 was observed. In fact, bivalves are not doing well lately, as can be illustrated by the Baltic telling *(Macoma balthica)*. Of this species abundance at Balgzand intertidal flats has steadily decreased (Drent et al., in prep) and instantaneous mortality rate has doubled since 1999 (R. Dekker, unpubl.). And at Groningen intertidal flats *M. balthica* does not get as old as it used to, i.e. there is increased adult mortality (P. Tydeman, unpubl.). During the last ca. 15 years at intertidal flats of the Dutch Wadden Sea recruitment failures in *M. balthica* have been more frequent than before (Beukema & Dekker 2005), especially at the lower tidal levels. Further, recruitment of *M. balthica* was shown to be negatively correlated with the abundance of shrimps *(Crangon crangon)* which are known to prey upon bivalve post-larvae. At higher intertidal levels such recruitment failures were not observed. Beukema & Dekker (2005) conclude that the centres of distribution of bivalves in their study area (Balgzand) have shifted to higher intertidal levels with muddier sediments, and that this shift is largely caused by increased epibenthic predation pressure (by shrimps *Crangon crangon)* which is facilitated by the occurrence of milder winters. Most recent data (not shown in Fig. 2), however, show a significant recovery of bivalve biomass at Balgzand in 2005-2006.

One could hypothesise that bivalves and polychaetes compete for food, and that decreasing phytoplankton grazing by decreasing bivalve populations provide a larger food supply to polychaetes in the form of algae eventually being deposited on the sediment. The observations by Beukema et al. (2002) show such a direct dependency of local benthic communities of algal food, but do not suggest any competition between suspension feeders (mainly bivalves) and deposit feeders (largely polychaete). Experiments by Kamermans et al. (1992) could not demonstrate any interspecific competition for food between the deposit feeding bivalve *Macoma balthica* and the suspension feeder *Cerastoderma edule.* It may be worthwhile, however, to use the obtained monitoring data from the Wadden Sea to test Levinton's (1972) hypothesis regarding interspecific competition for food in deposit feeding rather than in suspension feeding communities.

Conclusions

Bivalve biomass, making up 40-60% of total macrozoobenthic biomass, strongly fluctuates, reflecting the effect of the winter (mild or severe) on recruitment success. The total biomass of polychaetes tends to continue to increase. At the same time riverine nutrient discharges into the Wadden Sea decrease, thus not supporting the hypothesis of a causal relationship between polychaete biomass and eutrophication. Polychaete biomass, however, is larger in the more eutrophicated southern, than in the less eutrophicated northern part of the Wadden Sea.

References

Beukema, J.J., Cadée, G.C. & Dekker, R. (2002) Zoobenthic biomass limited by phytoplankton abundance: evidence from parallel changes in two long-term data series in the Wadden Sea. Journal of Sea Research 48: 111-125.

Beukema, J.J. & Dekker, R. (2005) Decline of recruitment success in cockles and other bivalves in the Wadden Sea: possible role of climate change, predation on postlarvae and fisheries. Marine Ecology Progress Series 287: 149-167.

Essink, K., Beukema, J.J., Madsen, P.B., Michaelis H. & Vedel, G.R. 1998 Long-term development of biomass of intertidal macrozoobenthos in different parts of the Wadden Sea. Governed by nutrient loads? Senckenbergiana maritima 29: 25-35.

Drent, J., Beukema, J.J., Dekinga, A., Dekker, R., Essink, K., Kraan, C., Piersma, T. & Waasdorp, D. The decline of Macoma balthica in the Wadden Sea. (in prep.)

Kamermans, P., Van der Veer, H.W., Karczmarski, L. & Doeglas, G.W. (1992) Competition in deposit- and suspension-feeding bivalves: experiments in controlled outdoor environments. Journal of Experimental Marine Biology and Ecology 162: 113-135.

Madsen, P.B., Toudal, K., Larsen, H., Laursen, J.S. & Rasmussen, T.H. (2005) Vadehavet. Status og udvikling 1989-2004. NOVANA. Amternes Vadehavssamarbejde. Ribe Amt, Sønderjyllands Amt. May 2005, 142 pp.

Kröncke, I., Zeiss, B. & Rensing, C. (2001) Long-term variability in macrofauna species composition off the island of Norderney (East Frisia, Germany) in relation to changes in climatic and environmental conditions. Senckenbergiana maritima 31: 65-82.

Levinton, J. (1972) Stability and trophic structure in deposit-feeding and suspension-feeding communities. American Naturalist 106: 472-486.

Rachor, E. (1990) Changes in sublittoral zoobenthos in the German Bight with regard to eutrophication. Netherlands Journal of Sea Research 25: 209-214.

TMAP 2000: TMAP Manual, version June 2000. – Common Wadden Sea Secretariat, Wilhelmshaven.

Van Beusekom, J.E.E., Bot, P.V.M., Goebel, J., Hanslik, M., Lenhart, H., Pätsch, J., Peperzak, L., Petenati, T., Reise, K. (2005). Eutrophication. In: Essink, K., Dettmann, C., Farke, H., Laursen, K., Luerssen G., Marencic, H. and Wiersinga, W. (eds.), Wadden Sea Quality Status Report 2004: pp. 141-154. Wadden Sea Ecosystem No. 19, Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group, Wilhelmshaven, Germany.

Van Beusekom, J.E.E. (2006) Eutrophication of the Wadden Sea: Present status and prospects. (this volume).

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Winter survival of mussel beds in the intertidal part of the Dutch Wadden Sea

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Every winter, mussel beds in the tidal area of the Dutch Wadden Sea disappear due to storm and predation. The Dutch government only allows fishing of juvenile mussels on newly formed mussel beds if these have a low chance of surviving the following winter. However, at presence the mussel bed area that disappears during winter is unknown. Here, we present the distribution of mussel beds in the Dutch Wadden Sea from 1994 to 2003. We determined the spatial contour of present mussel beds in autumn and spring using GPS. For the first time, we can quantify winter losses and average winter survival. We show that almost 40% of all mussel bed area disappears every winter. Of all newly formed beds, 50% did not survive their first winter. The best areas for development of mature mussel beds are positioned south of Ameland and Schiermonnikoog and at Wierumer Wad along the Frisian coast. Furthermore, we compare average winter survival with a habitat suitability map.

Key words: mussel beds, Mytilus edulis, population dynamics, population stability, Wadden Sea, winter survival

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Introduction

Intertidal beds of the blue mussel *(Mytilus edulis)* are important biogenic structures in the Wadden Sea ecosystem. The beds serve as habitat and as an important food source for a number of species (de Vlas et al. 2005). For example, many birds eat the mussels or rely on the organisms that occur in and around the mussel bed (Dankers et al, 2003).

The larvae or spat of the blue mussel settle in May/June (Van de Koppel et al. 2005). After the settlement of larvae, which is also known as spat fall, a new mussel bed can be formed consisting of a monolayer of mussels. Between August and November a new bed rises 30-40 cm above the surrounding sand flat, due to sedimentation of considerable amounts of fine silt (Hilgerloh et al. 2003). After winter, sand and shells wash in and settle between the mussels. As beds mature, they can develop into a physically solid structure because the accumulated silt consolidates and forms a clay layer. For a detailed review on the development of mussel bed see e.g. Dankers et al. (2001).

The area of mussel beds in the Wadden Sea demonstrates large fluctuations in time due to the erratic amount of spat fall and due to environmental disturbances such as ice cover and storms (Beukema et al. 1993, Nehls & Thiel 1993, Nehls et al. 1997). Especially new mussel beds are vulnerable to these disturbances, because they are easily washed away. Only in sheltered areas, where the impact of storms and ice is less severe, mussel beds can develop into mature beds (Nehls et al. 1997, Nehls & Thiel 1993). When a mussel bed is clearly recognizable over many years, it is considered as a so-called stable bed (Brinkman et al. 2003, de Vlas et al. 2005).

In the early nineties, intertidal mussel beds in the Dutch Wadden Sea almost disappeared due to ongoing fisheries and a low amount of spat fall (Dankers et al. 1999). In 1993, the Dutch government took action to protect important habitats, such as mussel beds and closed permanently 25% of the intertidal area for shellfish fisheries (Ens et al. 2004, Dankers et al. 2001). In 1999, additional 10% of the intertidal area that was believed to be suitable for the development of mussel beds was closed for mussel fisheries (Dankers et al. 2001).

At present, the aim for Dutch Government management plan is a target area of 2000 ha of mussel beds that survived at least one winter in the entire Dutch Wadden Sea. Fisheries on newly formed mussel beds outside the above-mentioned closed areas are only allowed if the total mussel bed area is larger than the target. Even if this condition is met, fishing of juvenile mussels on a specific mussel bed is only allowed if this mussel bed has a low chance of surviving the following winter.

In order to be able to implement this policy, we need to 1) know the area of mussel beds on a yearly basis and 2) have a better understanding on the survival chance of mussel beds. Brinkman et al. (2002) present a habitat suitability map of the intertidal areas of the Dutch Wadden Sea based on the presence of mussel beds in the period 1960-1970 and several environmental characteristics. This map proposes classes of suitability for the natural establishment and survival of mussel beds (see also Brinkman & Bult 2002). Here, we monitored the distribution of mussel beds in the Dutch Wadden Sea from 1994 to 2003. We determined the spatial contour of present mussel beds in autumn and spring using GPS. For the first time, we can quantify winter losses and average winter survival. Now we can also compare average winter survival with the habitat suitability map.

Material and methods

Mussel bed localisation

We located mussel beds in autumn and spring from autumn 1994 to spring 2004. To roughly locate new mussel beds, we performed aerial inspection flights in both spring and autumn and used information from fishermen and fishery inspectors. To measure the precise geographical location, size and shape of each mussel beds, we walked around each mussel bed with a GPS device during low tide. As such, we obtained the spatial contours of all beds.

A mussel bed consists of a collection of smaller patches. Therefore, the boundaries between a mussel bed and the surrounding tidal flat are not always clear (De Vlas et al. 2005). To define the boundaries of a single mussel bed, we used the following criterion conform De Vlas et al. (2005); a group of mussel patches less than 25 meters apart is considered as a bed, but only if at least 5% of the tidal flat is covered by these patches.

Contour reconstruction of unvisited beds

We could not visit every mussel bed during all surveys. Therefore, we needed to reconstruct the spatial contour of the unvisited beds in the missing point of the time-series. Here, we present a summary of the used method of reconstruction. For a detailed description in Dutch see Steenbergen et al. (2003).

We assume that: 1) mussel bed do not change shape during summer, 2) newly formed beds appear in autumn and 3) mussel beds can partially disappear in winter.

If a mussel bed could not be visited in spring, we used the contour of the mussel bed present in autumn of that same year instead. If a mussel bed could not be visited in autumn, we used the contour of the mussel bed present in spring of that same year instead. If a newly formed mussel bed could not be visited in autumn, or an older mussel bed could not be visited in both spring and autumn of the same year, we used the contour of the mussel bed present in spring of the following year instead. In the latter case, there can be a systematic underestimation of the area of mussel beds, because substantial parts of a mussel bed can disappear during winter season. To reduce this underestimation during the surveys, we prioritised the newly formed beds in autumn and those beds that had not been visited in autumn, in spring.

Reconstruction of unvisited beds was therefore possible until spring 2003. In spring, we visited 65% of the total mussel bed area and therefore reconstructed 35%. In autumn, we visited 42% of the total mussel bed area and reconstructed 58%.

Data analysis

We used Arcview version 3.2 (ESRI) to analyse the geographical data. If mussels at a specific location were present in autumn and the subsequent spring, they survived winter. The average winter survival of mussels was calculated by dividing the number of winters that the mussels survived by the number of times mussels settled at the same location. For example, we consider a particular location in the investigated time series where mussels successfully settled in the first year, survived two winters and did not settle again. This location would be classified with an average winter survival of two (two divided by one). If in the fifth year mussels would settle again on this location that survive for three winters, the average winter survival equals 2.5 (five winters divided by two settlements). Because mussel beds almost never disappeared completely, mussel beds were divided into several parts with different average survival.

To calculate the percentage of the lumped area that survived either zero or one winter(s) this area was divided to the total mussel bed area that had been present up to and including autumn 2002. To calculate the percentage of the area that survived (more than) two winters this area was divided to the total mussel bed area that had been present up to autumn 2002. To calculate the percentage of the area that survived three winters this area was divided to the total mussel bed area that had been present up to autumn 2001. And so on. All data are presented as mean±SD.

Winter losses

We assume that the mussel beds are lost only due to natural effects, but we are aware of two fishing activities (De Vlas et al. 2005). Firstly, in the autumn of 1994, some fishery was allowed on newly formed beds of the 1994 spat fall. However, most of the newly formed beds - both fished and un-fished - disappeared completely due to severe storms before the survey in spring 1995 (De Vlas et al. 2005, Ens et al. 2004). Secondly, restricted experimental fisheries were carried out in 2001 on beds that were considered unstable to test the hypotheses that moderate fishery could restore the stability of young beds. Also in this case both fished and unfished beds were destroyed by autumn and winter storms (De Vlas et al. 2005; Smaal et al. 2003). We assume that the above-mentioned two fishing activities have a negligible on the monitored mussel bed area.

Results

From autumn 1994 until spring 2003, 9500 ha of the intertidal area were covered with mussel beds for at least one season. The total mussel bed area ranged from 451 ha in the spring of 1998 to almost 5000 ha in the autumn of 2001 (Fig. 1).

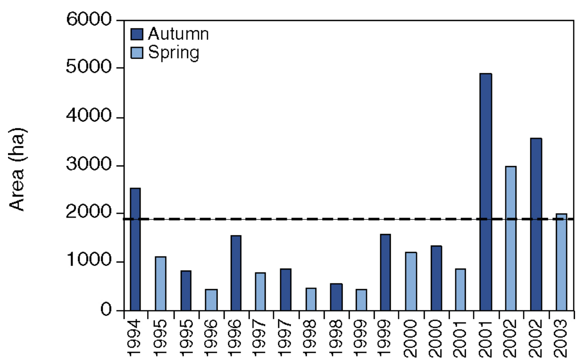

Figure 1. Development of mussel beds in the intertidal part of the Dutch Wadden Sea from autumn (au) 1994 until spring (sp) 2003. Dotted line indicates target area of 2000 ha.

The total mussel bed area in the Dutch Wadden Sea was very low in the nineties; in general there was less than 1000 ha present. In the nineties, the recovery of the mussel bed area started with good spat fall in 1994, but the winter losses were high and only 1000 ha remained. Until 2001 the total mussel bed area was below 2000 ha. The spat fall in autumn 2001 resulted in more than 2000 ha for the first time in seven years.

Almost 5000 ha of mussel beds were recorded of which 60% survived the winter period. The area of winter losses was 39.3 ± 12.6% (n = 9) and varied from 16.5% in the winter of 1998/1999 to 56.6% during the winter of 1994/1995 (Fig. 2). On 17% of the locations, mussels settled more then once.

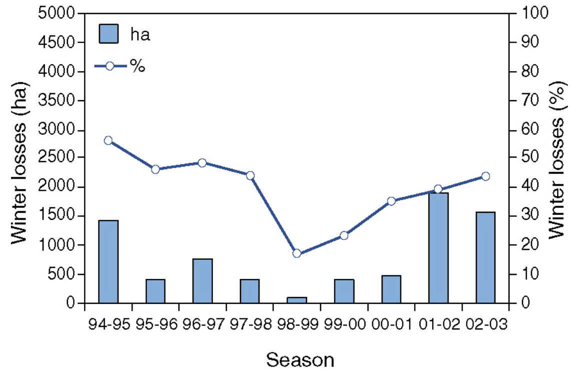

Figure 2. Yearly winter losses of mussel bed area in the intertidal part of the Dutch Wadden Sea since 1994, in hectares (left scale) and percentages (right scale).

The majority of mussel beds are located in the eastern part of the Dutch Wadden Sea (Fig. 3). More than half of the total mussel bed area did not survive the first winter (Fig. 4).

In the subsequent winters, the area roughly decreased by a two-fold: 27.8% survived one winter and 15.8% survived two winters. Of all the mussel bed area that was formed before autumn 2002, 22% survived two or more (2-9) winters. Only 1.3% of the area was formed before autumn 1994 and still present in spring 2003. These 32 ha of mussel beds therefore survived at least 9 winters. The mussel beds with large parts surviving more then four winters were situated at Wierummer Wad along the Frisian coast, or south of the islands Ameland (inset Fig. 3) and Schiermonnikoog.

Discussion

Our surveys show that 39.3 ± 12.6% (n = 9) of the mussel bed area in autumn disappeared during the winter season in the period 1994-2003. In many cases, mussel beds did not disappear completely; parts of beds could survive up to 4 years or more. Especially large parts of newly formed beds disappeared; 51.5% of the mussel bed area did not survive the first winter (Fig. 4). Parts of mussel beds that survived their first winter, still have a large change to disappear during following winters.

Winter losses are probably mainly caused by storms. Zwarts & Ens (1999) suggest that predation of birds can have a substantial effect, especially when only a few mussel beds are present. However, our data do not indicate higher winter loss percentages of mussel bed area in poor years. For example, in 1998-1999 the lowest winter loss (16.5%) co-occurred with the lowest area in autumn (540.5 ha).

We compared the average winter survival with the habitat suitability map of Brinkman et al. (2002).

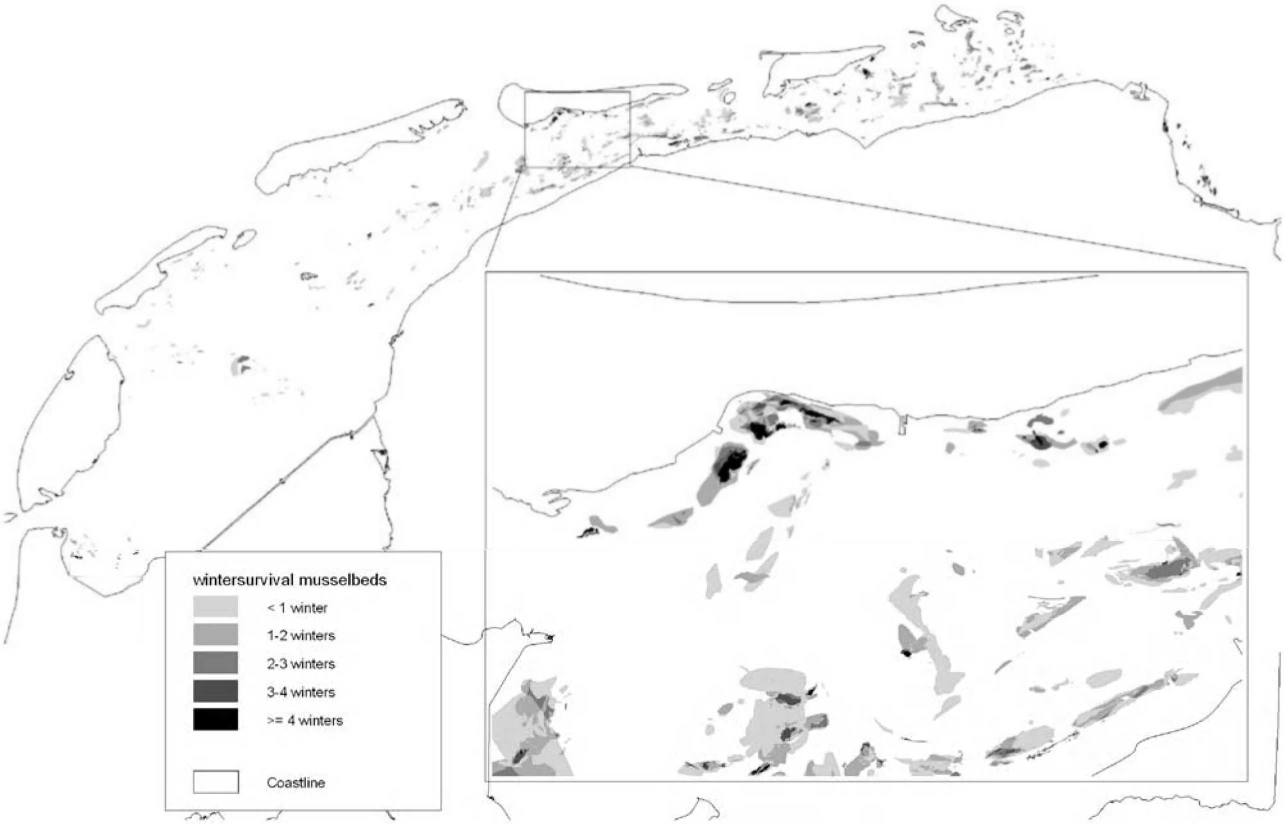

Figure 3. Average winter survival of (parts of) mussel beds in the intertidal of the Dutch Wadden Sea. The islands Ameland (A), Schiermonnikoog (B) and the Wierummer Wad along the Frisian coast (C) are indicated.

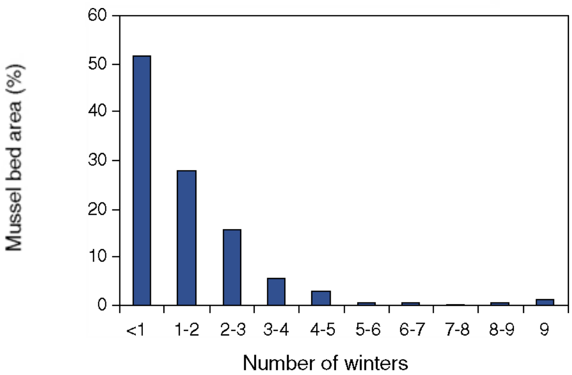

Figure 4. Average winter survival of the total mussel bed area that has been present in the intertidal of the Dutch Wadden Sea between autumn 1994 and spring 2003.

Average winter survival was 2 and 1.5 winters for class 1 and 2, respectively. These first two classes comprise the most suitable areas for the development of mussel beds and cover only 2% of the Wadden Sea. In the remaining part of the Wadden Sea, however, no major fluctuations in average winter survival were found (around 1 winter; Steenbergen et al. 2005). According to our data, the best areas for development of mature mussel beds are the areas south of the eastern islands, and at Wierummer Wad along the Frisian coast. These areas correspond with the 2% best areas suggested by the habitat suitability map.

Nehls et al. (1997) distinguished two types of mussel beds in the Wadden Sea of Schleswig-Holstein, Germany: dynamic or unstable beds and stable beds. Unstable beds were only present for some consecutive years and found in locations that were exposed to storms and ice. Stable beds were present for many years and found only at sheltered locations where the impact of storms and ice was less severe. We can conclude that mussel beds in the Dutch part of the Wadden Sea, which sustained over longer periods of time, all appear to be situated in sheltered areas. This seems consistent with the situation in the Niedersachsen (Germany) part of the Wadden Sea (Herlyn et al, 1999).

Although locations of stable mussel beds have been constant over decades, the total mussel bed area was highly variable in time (Dankers & Koelemaij 1989, Nehls & Thiel 1993). The unstable beds are of interest to mussel fisheries. In the investigated period from 1994 to 2003, a large area (83% of 9500 ha) of the intertidal area was covered with mussels only once due to erratic spat fall. With such a high spatial variability, it is not yet possible to predict future locations of unstable beds based only on observed winter survival.

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References

Beukema, J.J., Essink, K., Michaelis, H. & Zwarts L. 1993: Year-to-year variability in the biomass of macrobenthic animals on tidal flats of the Wadden Sea: how predictable is this food resource for birds? - Netherlands Journal of Sea Research 31: 319-330.

Brinkman, A.G. & Bult, T. 2002: Geschikte eulitorale gebieden in de Nederlandse Waddenzee voor het voorkomen van meerjarige natuurlijke mosselbanken. (In Dutch). - Alterra repport 456: 1-306.

Brinkman, A.G., Dankers, N. & van Stralen, M. 2002: An analysis of mussel bed habitats in the Dutch Wadden Sea. – Helgoland Marine Research 56: 59-75.

Brinkman, A.G., Bult, T., Dankers, N., Meijboom, A., den Os, D., van Stralen, M.R. & de Vlas, J. 2003: Mosselbanken; kenmerken, oppervlaktebepaling en beoordeling van stabiliteit. (in Dutch). - Alterra rapport 707: 1-70.

Dankers, N. & Koelemaij, K. 1989: Variations in the mussel population of the Dutch Wadden Sea in relation to monitoring of other ecological parameters. - Helgolander Meeresuntersuchungen 43: 529-535.

Dankers, N., Herlyn, M., Sand, Kristensen, P., Michaelis, H., Millat, G., Nehls G. & Ruth, M. 1999. Blue mussels and Blue mussel beds in the littoral. In: De Jong, F., J. Bakker, C. van Berkel, K. Dahl, N. Dankers, C. Gätje, H. Marencic & P. Potel (Eds.); Quality Status Report Waddensea Ecosystem No. 9. Common Waddensea Secretariat: 141–145.

Dankers, N., Brinkman, A.G., Meijboom, A. & Dijkman, E. 2001: Recovery of intertidal musselbeds in the Waddensea; use of habitatmaps in the management of fishery. - Hydrobiologica 465: 21-30.

Dankers, N.M.J.A., Meijboom, A., Cremer, J.S.M., Dijkman, E.M., Hermes, Y. & Marvelde, L. 2003: Historische ontwikkeling van droogvallende mosselbanken in de Nederlandse Waddenzee. (In Dutch). - Alterra-rapport 876: 1-114.

De Vlas, J., Brinkman, B., Buschbaum, C., Dankers, N., Herlyn, M., Sand Kristensen, P. Millat, G., Nehls, G., Ruth, M., Steenbergen, J. & Wherman, A. 2005: Intertidal blue mussel beds. In: Essink et al. (Eds.), Wadden Sea Quality status report 2004 Wadden Sea ecosytem No. 19. Trilateral monitoring and assessment group. Common Wadden Sea secretariat.

Ens, B.J., Smaal, A.C. & de Vlas, J. 2004: The effect of shellfish fishery on the ecosystems of the Dutch Wadden Sea and Oosterschelde. - Alterra-rapport 1011; RIVO-rapport C056/04; RIKZ-rapport RKZ/2004.031: 1-212.

Hilgerloh, G., Herlyn, M. & Michaelis, H. 1997: The influence of predation by herring gulls Larus argentanus and oystercatchers Haematopus ostralegus on a newly established mussel Mytilus edulis bed in autumn and winter. Helgoländer Meeresuntersuchungen 51: 173-189.

Herlyn, M., Millat, G., Michaelis, H., 1999. Einfluss der Besatzmuschelentnahme auf die Entwicklung eulitoraler Neuansiedlungen von Mytilus edulis L. im Niedersächsischen Wattenmeer. Niedersächsisches Landesamt für Ökologie – Forschungsstelle Küste 9/99: 1-27.

Nehls, G., Hertzler, I. & Scheiffarth, G. 1997: Stable mussel Mytilus edulis beds in the Wadden Sea – They're just for the birds. - Helgoländer Meeresuntersuchungen 51: 361-372.

Nehls, G. & Thiel, M. 1993: Large-scale distribution patterns of the mussel Mytilus edulis in the Wadden sea of Schleswig-Holstein: do storms structure the ecosystem? - Netherlands Journal of Sea Research 31(2): 181-187.

Smaal, A.C., van Stralen, M.R., Kersting, K. & Dankers, N. 2003: De gevolgen van gecontroleerde bevissing voor bedekking en omvang van litorale mosselzaadbanken- een test van de 'Jan Louw' hypothese en van de mogelijkheden voor natuurbouw. (In Dutch). - RIVO-rapport C022/04: 1-93.

Steenbergen, J., Stralen, M.R., van, Baars, J.M.D.D. & Bult, T.P. 2003: Reconstructie van het areaal litorale mosselbanken in de Waddenzee in de periode najaar 1994 – voorjaar 2002. (In Dutch). – RIVO-rapport. C076/03: 1-36.

Steenbergen J., Baars, J.M.D.D., Bult, T.P. 2005: Een analyse van de winterverliezen van litorale mosselbanken in de Waddenzee (periode 1994-2003). (In Dutch). - RIVO-rapport. C040/05: 1-27.

Van de Koppel, J., Rietkerk, M., Dankers, N. & Herman, P. M. J. 2005: Scale-dependent feedback and regular spatial patterns in young mussel beds. - American Naturalist 165: E66-E77.

Zwarts, L. & Ens, B.J. 1999: Predation by birds on marine tidal flats. In: Adams, N.J. & Slotow, R.H. (Eds.); Proceedings of the 22nd international ornithological congress in Durban. BirdLife South Africa, Johannesburg: 2309-2327.

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The Danish Wadden Sea; fishery of mussels *(Mytilus edulis L.)* in a Wildlife Reserve?

Per Sand Kristensen & Rasmus Borgstrøm

Sand Kristensen, P. & Borgstrøm, R. 2005: The Danish Wadden Sea; fishery of mussels *(Mytilus edulis L.)* in a Wildlife Reserve? In: Monitoring and Assessment in the Wadden Sea. Proceedings from the 11. Scientific Wadden Sea Symposium, Esbjerg, Denmark, 4.-8. April, 2005 (Laursen, K. Ed.). NERI Technical Report No. 573, pp. 113-122.

Mussels have been fished in The Danish Wadden Sea, an International Wildlife Reserve for many years. In the 1980's the mussel stock collapsed, and for a short period the food supply for birds was critically reduced. The number of mussel fishing licenses was drastically reduced, and since 1986 the mussel stocks have been monitored by the Danish Institute of Fisheries Research. Aerial photographs and mussel sampling have been used for estimation of bed area and for monitoring and assessment of the population. The mussel beds have varied between 1,192 ha in 1991 to 632 ha in 1996. In 1999 the total mussel beds were 1,051 ha. On the subtidal beds samples were collected by dredging using a commercial dredge and on the intertidal beds by a large number of frames. Combining these two factors the biomass was estimated. The biomass of mussel in The Danish Wadden Sea has varied considerably over the years. Minimum (5.840 t) and maximum (117.000 t) occurred in 2004 and 1993 respectively. Based on the biomass observed during autumn, the production of mussels for the next year was estimated. The estimated annual production was divided between birds and fishery in a way that at least 10,300 tons were allocated to the birds before a TAC was allocated the fishery. This management plan is intended to supply mussel foraging birds with sufficient food and to prevent overexploitation of the mussel population.

Key words: Mytilus edulis, aerial photography, GIS, image analysis, orthophotos, monitoring, assessment, biomass variation, food for birds, sustainability

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Introduction

The Wadden Sea covers a tidal area of approximately 10,000 km^2 in the south eastern North Sea between Den Helder in the Netherlands and Ho Bight in Denmark. The Danish part of the Wadden Sea is ca. 900 km^2. Three islands (Fanø, Mandø and Rømø) divide the Danish Wadden Sea into four tidal areas (Grey Deep, Knude Deep, Juvre Deep and Lister Deep between Rømø and Sylt), thus 500 km^2 are affected by tides. The blue mussel *(Mytilus edulis)* usually occurs in both subtidal and intertidal areas of the Danish Wadden Sea in beds of sizes from a few thousands m^2 up to a few km^2. Blue mussels form clusters on sand and mud bottom. Smaller beds (< one ha) may be very densely crowded with mussels (~ 70% cover). Since 1986 mussels abundance in the Danish Wadden Sea has been monitored using aerial photography and ground sampling (Munch-Petersen & Kristensen 1997 and 1989).

Mussel stocks in the Dutch and German Wadden Sea areas have also been monitored for many years. (Bult et al. 2000; Farke et al. 2004; Nehls et al. 2000; Nehls 2001 and Nehls & Ruth 2004, Stoddard 2003; Dankers et al. 2001; Ens et al. 2004; Herlyn 2005). The technique used in the three countries differs to a certain degree, but all monitoring programs estimate bed sizes (in hectares or square meters) and abundance. These data are used to support sustainable management of the population while ensuring sufficient mussel prey for foraging birds.

In 1992 48% of the Danish Wadden Sea was closed permanently for mussel fishing. The closed areas are ¾ of Ho Bight Juvre Deep and the southern part of Lister Deep at the border to the German Wadden Sea. Mussel fishing was only allowed in Hjerting Stream the south eastern part of Ho Bight, the southern part of Grey Deep and Knude Deep and the northern part of Lister Deep.

Since the beginning of the 1980's the mussels in the Danish Wadden Sea have been exploited at a high rate until the stock collapsed in 1987 (Munch-Petersen & Kristensen 1987, Kristensen & Laursen in prep). Since 1986 the Danish Institute of Fisheries Research (DIFRES) has monitored and assessed the mussel stock for authorities responsible for nature conservation and management of the fishery resources in the Danish Wadden Sea.

The estimation of bed sizes is based on aerial photographs, which have been improved throughout the whole period since 1986. In the early days black/white aerial photos were used, which to a certain extent made it possible to distinguish blue mussels from other organisms in the beds (Munch-Petersen & Kristensen 1987). From 1993 and onwards, colour photos were used to estimate mussel beds. The mussel beds were drawn on transparent plastic-folio and weighed to determine bed sizes (Kristensen 1994).

Introduction of the Geographical Information System (GIS) in 2002 made it possible to estimate the areas with mussels by digital image analysis by use of ortho photos (aerial photos corrected for terrain distortions etc.). Provided that the quality of the ortho photos and the physical parameters such as the tidal situation (low tide), clouds etc. are optimal, it is possible automatically to detect and estimate the sizes of mussel beds.

However, it is necessary systematically to take ground samples of the beds to determine the biomass of mussels alive.

The biomass of mussels in the Danish Wadden Sea has been estimated using these methods during the last 20 years to establish the amount of mussels necessary to sustain birds that depend on mussels for food before allocating mussels to the fishery.

This study describes the development of monitoring techniques and the assessment program performed since 1986 and the introduction and application of new techniques. A key element of the management of the mussel resources in the Danish Wadden Sea is that the population has to observe sustainable and must support a sufficient food supply for birds. In practice, this is accomplished by only allowing exploitation of the annual new mussel production (from October year one (x) to October the following year (x+1)).

Materials and methods

Stock assessment of mussels in the Danish Wadden Sea has been carried out using aerial photographs to estimate the mussel bed areas. These investigations have been combined with ground sampling to determine abundance (n/m^2) and biomass (kg/ m^2).

The total biomass of mussels in tons in the Danish Wadden Sea is determined by adding all bed size estimates per tidal area based on the aerial photographs and multiplying these figures with the biomass established through the field investigations for each tidal area respectively.

Before 1991 aerial photos in black/white have been used in planning the survey and monitoring of the mussel beds in the Danish Wadden Sea (Munch-Petersen & Kristensen 1987 and 1989) (Fig. 1A). However, some smaller and difficult beds with mussels were not recognizable on the b/w photographs (Munch-Petersen & Kristensen 1989) (Fig. 1B). After 1991 aerial colour photographs have been used to monitor mussels in the Danish Wadden Sea (Kristensen 1994 and 1995). The photos from 1991 until 1996 were taken from an altitude of 1,350 meters. Each photographic slide covered 1,852 * 1,852 m^2 (i.e. 1 sq. nautical mile).

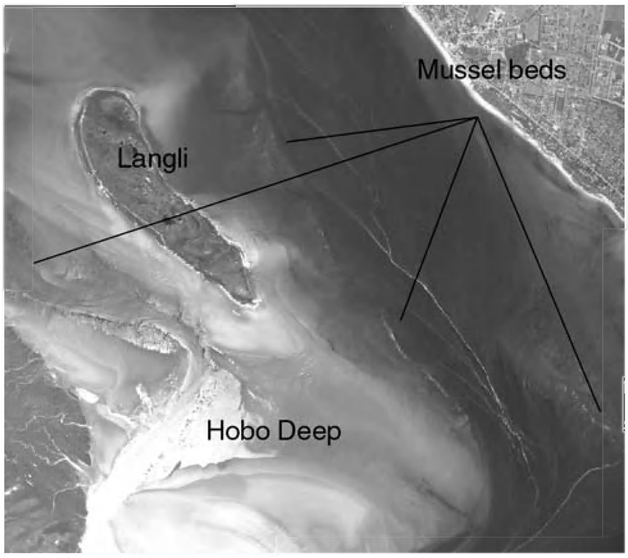


Figure 1A. Black and white aerial photo (1983).

Figure 1B. Aerial colour picture (1999).

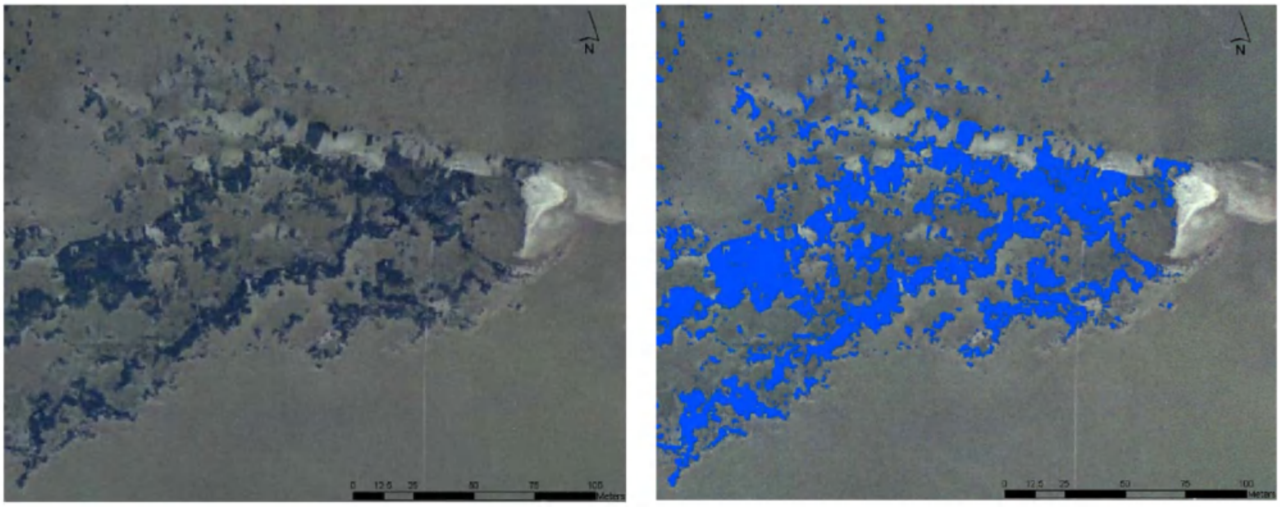


Figure 1C. Scanned ortho photo (2002); the blue areas on the right image indicate areas classified as mussel areas in the GIS analysis. (Note: each pixel in blue is 0.16 m^2)

After 1998 only regular colour ortho photos were taken every 2nd or 4th year in a scale 1:25,000. In 2004 digitisation of the colour photos was introduced to create ortho photos to identify mussel beds in a more precise way (Fig. 1C). The ortho photos were analysed by using GIS and an image classification analysis which made it possible to distinguish between presence and absence of mussels in squares (pixels) of 0.16 m^2 (Fig. 1C). Ground sampling is necessary to distinguish between living mussels and empty mussel shells. Mussels have been collected by using an iron frame (0.5 * 0.5 m^2) pressed over the mussels in the bed (see Fig. 2) or by collecting the mussels by dredging (commercial mussel dredge). The samples were frozen and analysed in the laboratory to estimate the size distribution and individual weights. From the stratified samples the abundance and biomass of mussels per m^2 of mussel bed were estimated.

Since 1990, a swept area sampling technique has been applied. The dredge samples taken by a commercial dredger (catch efficiency of 100 %) have been used to estimate the mussel biomass in the subtidal beds. Sampling stations have been randomly distributed in the fishing area covering between 10 and 12 km^2 respectively in Grey Deep south and north of Esbjerg Harbour (Munch-Petersen & Kristensen 2001). The tracks are of variable length and cover swept areas between 4 – 1,777 m^2 (Kristensen 1995 and 1996; Kristensen & Pihl 1998, 2001 and 2003). An example of dredge tracks and frame samplings in Ho Bight in the 2004 survey is shown in Figure 2. In the Ho Bight an area of 11 km^2 has been randomly dredged to determine the biomass of live mussels on 70 stations giving the mean biomass in kg pr. m^2 of bottom. Similar dredging has been performed south of Esbjerg in Grey Deep and Knude Deep within an area of 10 km^2. The used technique is the same in other Danish fishing areas for mussels (Kristensen & Hoffmann 2004; Kristensen 2001, 2002 and 2003).

In the laboratory samples were sorted into groups: whole living mussels, empty shells of mussels, and other organisms. At least 150 mussels are measured in shell length to nearest mm. The size distribution is recorded for each tidal area. The distribution by frequency is given for each tidal area. The frequency distribution of the mussels by their weight representation in the samples is estimated by transforming numbers to weight by use of the formula:

$$W = 0.09076 * L^{2.973726}$$

W is total wet weight in grams (shells included) and L is shell length in mm.

This estimation is carried out to establish the weight distribution of mussels in the sampled stock, where the regulation is maximum 10 % of mussels with $L \leq 50$ mm in shell length by weight. The eider ducks are assumed to cover around 60% of their food requirements by mussel meat. The oystercatchers and herring gulls cover on average 17% and 5% respectively of their food requirements by mussel meat (Gross-Custard personal communication). These figures are used in the estimations of the food consumption by birds in the Danish Wadden Sea. The annual average number of bird-days is given as the average bird- counts per day each month of the year over the years 1986 to 1999 multiplied by 365 days (Kristensen & Laursen in press) and (Laursen & Kristensen in press). The food consumption by birds is from the literature (Nehls 1995; Nehls et al. 1997; Kresten & Piersma, 1987; Kersten & Visser 1996; Speakman 1987; Zwarts et al. 1996, 1996a, 1996b and 1996c).

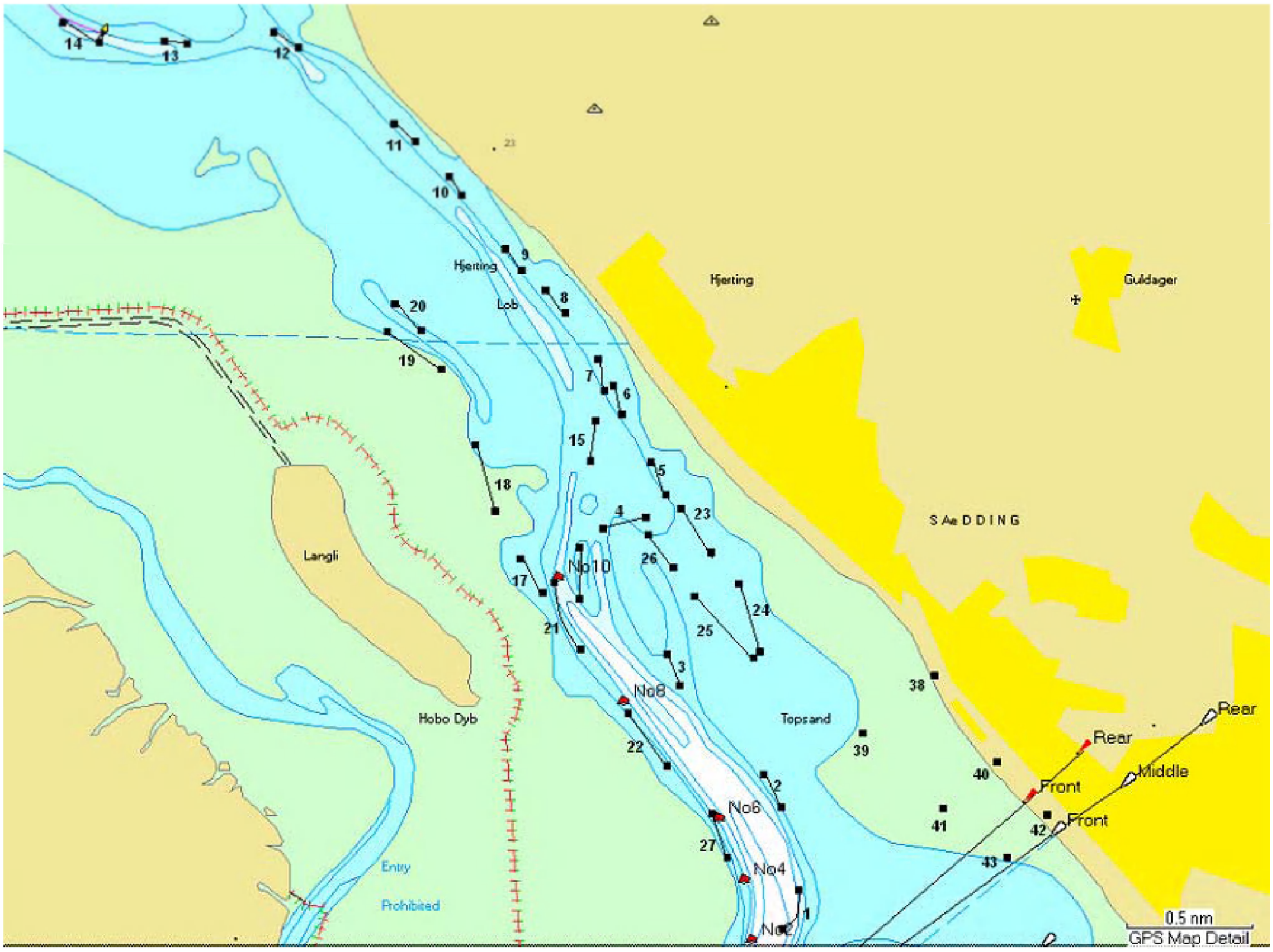


Figure 2. Frame and dredge sampling stations in the survey from September 2004 in Ho Bight. *Frame samples (No. 38-43).*

Results

The bed sizes in m² for each aerial photograph are given as figures for each tidal area (an example for Ho Bight in 2004 is shown in Tab. 1). The total areas with mussels in the Danish Wadden Sea in 2004 are shown in Table 2 (for other results please look Kristensen 1996; Pihl & Kristensen1997; Kristensen & Pihl 1998, 2001 and 2003; Kristensen et al. 2005)

There has been a decrease in the areas with mussels from 1991 to 1996 from 1,192 ha to 632 ha. In 1999 the areas were back to previous sizes of 1,051 ha (Fig. 3).

In 2004 the fishable biomass was estimated to 2,144 tons (Fig. 4). The non fishable biomass was estimated to 1,511 tons (Fig. 4) in the fishing areas. Besides these figures 2,191 tons of mussels were recorded in Juvre Deep (area closed for fishing).

Based on the estimated mean biomass an annual production is then established on basis of measurements of the average mortality and growth of mussels in the Danish Wadden Sea (Munch-Petersen & Kristensen 2001). The estimated biomass (B) in tons in October can be extrapolated to October the following year by multiplying biomass by 0.5 (taken from Munch-Petersen and Kristensen 2001) (Tab.2).

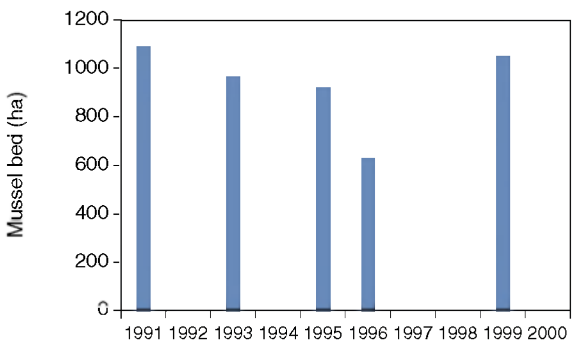


Figure 3. Intertidal and subtidal blue mussel beds (in ha) in the Danish Wadden Sea based on annual surveys in spring.

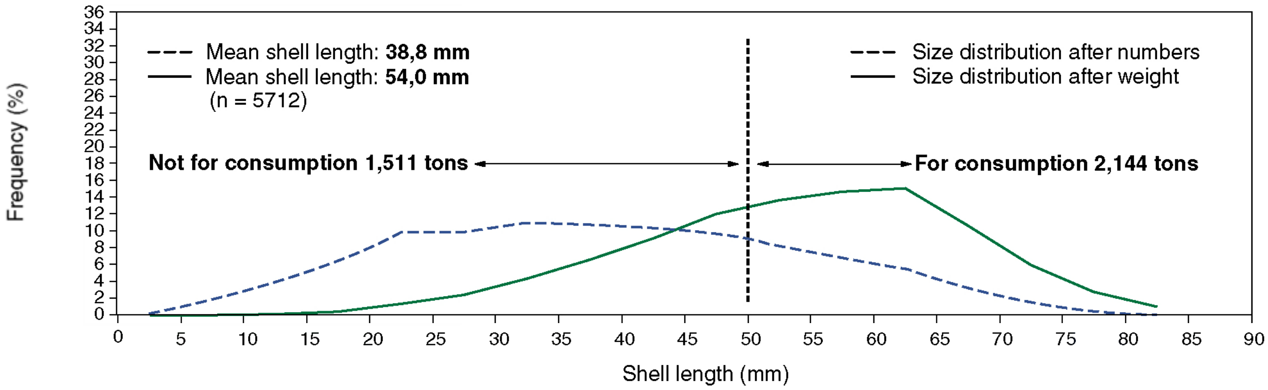
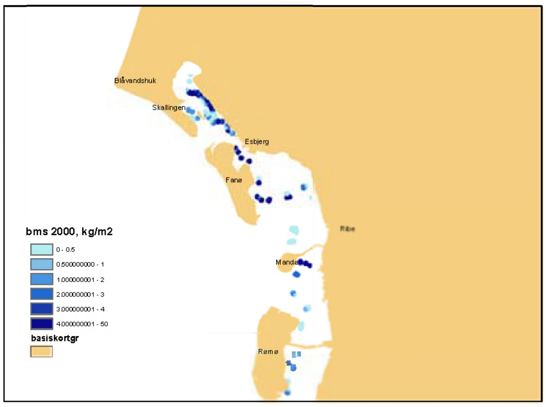


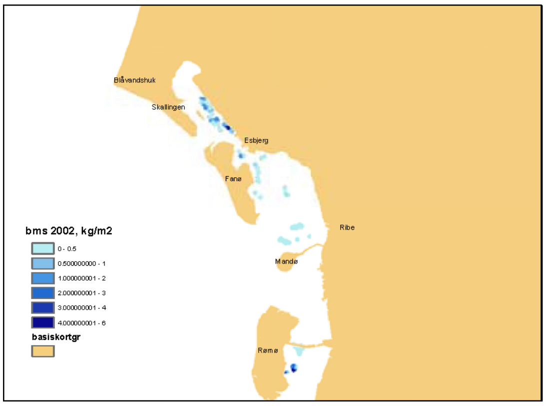
Figure 4. Size distribution of mussels in the Danish Wadden Sea in 2004 by numbers in samples, and by their weight representation in samples.

Table 1. The area (in km^2) and biomass (in kg/m^2) estimations of blue mussels in Ho Bight in 2004. *Both frame and dredge samples are given in the table.*

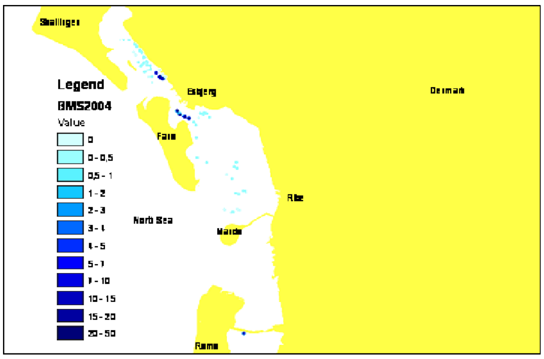
Estimated biomass of common mussels in Ho Bight in September 2004:	st nr.	Catch in kg	Sample method	Swept area in m^2	Mussels kg/m^2			**Total mean biomass tons**
	1	0,000	Dregde	660,60	0,00			
	2	4,137	Dredge	504,00	0,01			
	3	0,000	Dredge	462,60	0,00			
	4	25,074	Dredge	577,80	0,04			
	5	4,363	Dredge	482,40	0,01			
	6	93,067	Dredge	401,40	0,23			
	7	60,373	Dredge	448,20	0,13			
Area	8	27,512	Dredge	430,20	0,06			
in km^2:	9	12,282	Dredge	426,60	0,03			
11	10	89,658	Dredge	295,20	0,30			
	11	85,849	Dredge	401,40	0,21			
all samples are dredged	12	13,067	Dredge	421,20	0,03			
where dredging takes place	13	37,751	Dredge	300,60	0,13			
in areas both with and without	14	35,466	Dredge	464,40	0,08			
mussels giving a low biomass	15	45,313	Dredge	527,40	0,09			
	16	0,000	Dredge	694,80	0,00			
	17	144,041	Dredge	554,40	0,26			
	18	90,589	Dredge	959,40	0,09			
	19	0,000	Dredge	889,20	0,00			
	20	0,000	Dredge	504,00	0,00			
	21	26,263	Dredge	1002,60	0,03			
	22	48,790	Dredge	878,40	0,06			
	23	70,673	Dredge	703,80	0,10			
	24	75,174	Dredge	964,80	0,08			
	25	83,492	Dredge	1173,60	0,07			
	26	107,918	Dredge	552,60	0,20			
	27	0,000	Dredge	615,60	0,00			
	28	26,471	Dredge	23,58	1,12			
	29	0,000	Dredge	648,00	0,00			
	30	0,000	Dredge	455,40	0,00			
						Mean. biom. (kg/m^2):	**Standard error.**	
						0,112	0,078	
						Mean. biom.	1.232	1.232
Area	Mussels in the littoral beds september 2004 (frame samples)					max:	2.087	
in km^2:	(Note area surveyed applying GIS estimation (counting of pixels))					min:	377	
0,032706	0-samples are therefor omitted in the estimations							
	38	0,000	Frame	0,25				
Only the densly populated	39	3,416	Frame	0,25	13,66			
mussel beds are detected	40	0,000	Frame	0,25		Mean. biom.	**Standard**	
0-samples are omitted!	41	4,352	Frame	0,25	17,41	(kg/m^2):	**error.**	
	42	0,000	Frame	0,25		**15,018**	2,934	
	43	3,496	Frame	0,25	13,98	**Mean. biom.**	491	491
						max:	587	
						min:	395	
						All mean:		1.723
						max:	2.674	
						min:	772	



A: Mean biomass 49,107 tons



B: Mean biomass 16,601 tons



C: Mean biomass 5,840 tons

Figure 5. The development in the biomass of mussels in the Danish Wadden Sea in 2001 (A), 2002 (B), and 2004 (C).

The changes in the total biomass of mussels in the Danish Wadden Sea are shown in Figure 5A, 5B and 5C. There is a dramatic decrease from around 50,000 tons in 2000 (Fig. 5A) to only around 6,000 tons in 2004 (Fig. 5C).

Tabel 2. The total area (in km^2) monitored for mussels and the total estimated biomass of mussels alive (in tons) in the Danish Wadden Sea in September 2004. *The management related consequences for the fishery are mentioned.*

Year 2004	
Survey data:	
Swept area (dredging)	21,0 km^2
Aerial photographs (frame)	0,3 km^2
Annual production of mussels*	0,5
Biomass estimations:	
Average biomass	0,27 kg/m^2
Total biomass	5,840 tons
Biomass production	2,920 tons
Error of estimations	35%
Management planning:	
Quota for the fishery (season 2004-2005)	0 tons
Food for birds (one season)	8,760 tons

*From Munch-Petersen & Kristensen 2001

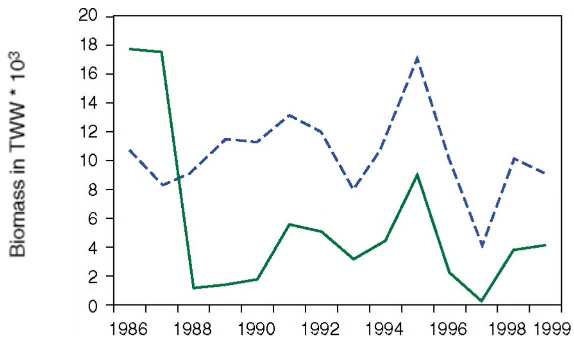


Figure 6. The removal pattern of mussels in total wet weight in the Danish Wadden Sea by birds (dashed line) and fishery (solid line) between 1986 and 1999.

Subtracting the estimated biomass year one from the extrapolated biomass year two gives a figure for the production (P) of mussels over one year. This production is allocated to birds and the fishery according to official management policy (Ministry of Food Agriculture and Fisheries). The estimated minimum ration for birds is at least 10,300 tons total wet weight, corresponding to 463 tons of AFDW of mussel meat, which on average can sustain at least 17 million bird days per year (Kristensen & Laursen in prep).

Since 1988 the management policy based on the survey and assessment of the mussel stock has resulted in a clear change in the exploitation and elimination of the mussels in the Danish Wadden Sea from a much higher exploitation level by the birds compared to the fishery as before 1987, where it was the other way around (Fig 6). The exploitation by fishery decreased substantially in 1986/1987 and has since varied between 38 tons in 2004 to 9,481 tons in 1995 (Fig. 7).

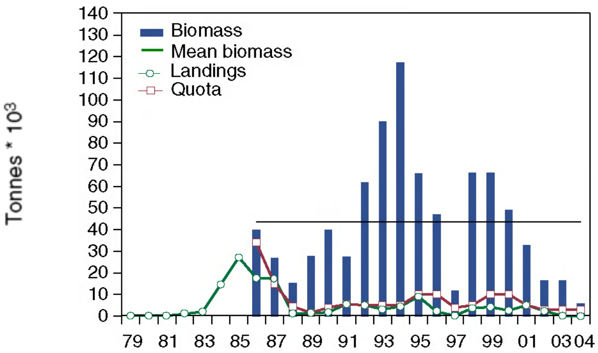


Figure 7. The development in the mussel biomass, landings, and fishing quota from the Danish Wadden Sea (1979-2004).

At the same time the consumption by birds has increased from 4,000 to 17,100 tons (Fig. 6). Since 2003 landings have been sporadic and lower than 260 tons annually. Due to the very low standing stock in the 2004 assessment and accordingly a very low production potential, the quota for the fishery in 2005 was set to zero.

Discussion

The main reason for monitoring and estimating the mussel stock in the Danish Wadden Sea has been to advise the Danish Ministry of Food Agriculture and Fisheries and the Ministry of the Environment on the total allowable catch and quotas for the fishery. At the same time the purpose was to take into account the sustainability of the mussel stock and to make sure that a sufficient food supply for bird species was not jeopardized by the fishery in the Danish Wadden Sea.

The biomass of mussels estimated at a certain time of the year (September - October) will produce a certain amount of mussels in coming years. The production estimate is based on knowledge of the growth and mortality of mussels in the Wadden Sea (Munch-Petersen & Kristensen 2001). Birds are ensured a minimum level of food and have been allocated at least 50% of the estimated production and not less than 10,300 tons per year during the last 15 years (Kristensen & Laursen in prep).

After 1990 the quota for the fishery has been between 2,000 and 10,000 tons. Between 1990 and 2004 the fishery has in average landed ca. 3,300 tons annually (between 38 and 8,931 tons) equal to around 6% of the estimated mean biomass. The exploitation has been higher in periods but very seldom over 10%. The data material on the stock assessment is delivered to the Directory of Fisheries and Nature and Forest Agency by the Danish Institute of Fisheries Research. In the last couple of years the landings have been very low and below 260 tons annually.

In 1990 the number of licenses was reduced from forty to five. In addition, in 1992 48% of the Danish Wadden Sea was closed for mussel fishing. The fishery was subjected to obey a new regulation law in which an annual, daily and weekly quota was set for the fishery negotiated between the Ministry of the Environment (The Forest and Nature Agency) and The Ministry for Food, Agriculture and Fisheries (Directory of Fisheries).

Similar tasks are also important in the other Wadden Sea countries as The Netherlands and Germany. However the mussels in the Dutch and the German Wadden Sea are primarily cultured, in which newly settled seed mussels are transplanted from the settling beds to culture beds. The transplantation has the purpose to improve production, growth and meat yield in the cultured mussels.

The program and management plans for the mussel stocks in the Danish Wadden Sea follow monitoring and recording tasks similar to the programs performed in the Dutch and the German Wadden Sea. There are only minor differences between the monitoring programmes between the three Wadden Sea countries. Aerial photographing is the same although the scaling varies between the countries. These variations are discussed and adapted in the Trilateral Monitoring and Assessment Program group at annual meetings (Marencic 2001). There are also minor differences in the field survey programs between the three Wadden Sea countries.

However, the largest step forward in the techniques used in monitoring of mussels in the Wadden Sea, was made by digitising the aerial photos to ortho photos to make them much more applicable for estimating the sizes of the mussel beds. However, it is important to stress that the most reliable results by using digitised aerial photos can only be achieved on intertidal beds. Measuring bed sizes in the subtidal beds by using the same technique depends on the tidal situation (low tide only), the position of the sun (the angle with the surface of the earth), reflection from the sea surface and cloud formations etc. Fortunately the Danish Wadden Sea is relatively shallow with a maximum water depth < 5 meters at low tide in the main parts, which makes it possible to interpret the sizes of the subtidal mussel beds in large parts of the Danish Wadden Sea using aerial photos. The digitising technique now makes it possible to zoom in and out in a scale, making it easier to draw a more precise line around the bed with mussels, excluding the application of cover percentages. Satellite images have been considered in the Danish monitoring program for mussels in the Wadden Sea for producing images closer to the sampling time in the field. However the cost, resolution and other problems have so far postponed the use of that technique (Munch-Petersen & Kristensen 1989).

To have the best reliable measurement of the mussel bed sizes it is important to employ in situ field sampling in combination with aerial photographs. This is especially important if an objective is to monitor the annual and seasonal changes in the mussel beds. In this study the estimation of the biomass of the standing stock and annual production is the most essential objective. In that context, only the relative bed sizes were important in the estimation of the total biomass of mussels in The Danish Wadden Sea combined with the measured biomass of live mussels per square meter of mussel bed based on in situ samplings.

Aerial photography and sampling in the field are easy to conduct on intertidal mussel beds. Monitoring of mussels in the subtidal beds demands other methods. In the Danish Wadden Sea we have used dredging on random subset of sampling stations within stable areas.

It is essential that the monitoring and assessment programs for the bivalve species in the Wadden Sea are coordinated to enable comparison of changes and developments in these stocks through the whole of the Wadden Sea, which is one of the most important marine wetlands in Europe. Coordinated assessment facilitates the exploitation of mussels in the Danish Wadden Sea by humans and the bird populations. Many bird species depend on the Wadden Sea as resting and feeding areas either permanently as residents or as migrants from their winter residence to their summer residence and visa versa. The declines in the bivalve stocks of cockles and mussels have had great importance for birds especially in the Dutch Wadden Sea, where high mortality rates have been observed among birds especially eiders (Ens et al., 2004). There has been less mortality of birds in the German and the Danish Wadden Sea. The exploitation level of cockles and mussels has in many years been higher in the Dutch Wadden Sea compared to the German and the Danish Wadden Sea (Dijkema 1997 and Seaman & Ruth, 1997). During the last 15 years the exploitation level of mussels in The Danish Wadden Sea has been limited to the production which the monitored standing stock was capable of producing over the coming year. This allocation rule has been applied to safeguard sufficient food supply for the bird species depended of mussels and cockles as food. No such estimations are used in The Netherlands or in Germany. This is probably due to the different exploitation forms in Germany and in The Netherlands, where the new settled blue mussels spat are transplanted and cultured on culture lots. In Denmark fishery is only allowed on the natural beds and culture is prohibited.

Some concern can be expressed for the future, if one looks at the present situation with the lowest biomass observed in the last 20 years in spite of the strict management program, which has been applied during the last 15 years in the Danish Wadden Sea. The lack of recruitment and scanty spat fall the last years in the whole of the Wadden Sea can result in lower biomasses of mussels and cockles and accordingly less food for birds and less mussels and cockles to fish. Knowledge on stock developments and factors affecting production and survival of mussels will in the future be more important than previously.

As in the other Wadden Sea countries, the Danish Wadden Sea is a Wildlife Reserve and appointed as a Ramsar area, Bird protection area under the EU-Bird Directive, and a NATURA-2000 area under the EU-Habitat Directive. A strong management of the exploitation of fishable stocks, which have been implemented the last fifteen years in the Danish Wadden Sea, is therefore essential for all the involved authorities. The new techniques applied may improve the assessment and reduce variations and uncertainties on estimates of stock size and annual production rates. These parameters are used to advice the authorities on TAC and quotas for the fishery.

As the question raised in the title implies, there may be problems fishing mussels in a nature Wildlife Reserve such as the Danish Wadden Sea. It is however the authors opinion, that it is possible to fish mussels in a Wildlife Reserve if the fishery is conducted at a level which does not affect interaction with other species or the eco-system.

References

Bult T.P., B.J. Ens, R.L.P. Lanters, A.C. Smaal & L. Zwarts. 2000. Korte Termijn Advies Voedselreservering Oosterschelde. Rapport RIKZ/ 2000.042. pp 60.

Dankers, N., A.G. Brinkman, A. Meijboom & E. Dijkman. 2001. Recovery of intertidal mussel beds in the Waddensea: use of habitat maps in the management of the fishery. In: Developments in Hydrobiology Coastal Shellfish a Sustainable resource. Ed. G. Burnell. Hydrobiologia 465: 21-30.

Dijekema R. 1997. Molluscan Fisheries and Culture in the Netherlands. In: C. L. Mackenzie, Jr., V. G. Burrel, Jr., A. Rosenfield, and W. L. Hobart (eds.), The history, present condition, and future of the molluscan fisheries of North and Central America and Europe. U.S. Dep. Commer., NOAA Tech. Rep. 129, p. 115 - 135.

Ens. J.B., A. C. Smaal & J. De Vlas. 2004. The effects of shellfish fishery on the ecosystems of the Dutch Wadden Sea and Oosterschelde. Final report on the second phase of the scientific evaluation of the Dutch shellfish fishery policy (EVAII). Alterra-rapport 1011.doc; RIVO-rapport C056/ 04; RIKZ-rapport RKZ-/2004.031.

Gross-Custard, J. 2001. Personal communication

Kersten, M. & T. Piersma. 1987. High levels of energy expenditure in shorebirds: metabolic adaptations to an energetically expensive way of life. Ardea 75: 175-187.

Kersten, M. & W. Visser. 1996. The rate of food processing in the Oystercatcher: food intake and energy expenditure constrained by a digestive bottleneck. Funct. Ecol. 10: 440-448.

Kristensen P.S. 1994. Blåmuslingebestanden i det danske Vadehav og blåmuslingefiskeri (1991 – 1993). (The common mussel stock in the Danish Wadden Sea and mussel fishery (1991 – 1993)). DF&H-rapport nr. 476. pp. 56.

Kristensen P.S. 1995a. Aerial surveys, biomass estimates, and elimination of the mussel population (Mytilus edulis L.), in the Danish Wadden Sea, 1991-1994. ICES Shellfish Committee. CM. 1995/K: 44. pp. 22.

Kristensen P.S. 1995b. Blåmuslingebestanden i det danske Vadehav august 1995. (The common mussel stock in the Danish Wadden Sea in August 1995). DFU-rapport nr. 01-95. pp. 27.

Kristensen P.S. 1996. Blåmuslingebestanden i det danske Vadehav efteråret 1996. (The common mussel stock in the Danish Wadden Sea autumn 1996). DFU-report nr. 36-97. pp. 27.

Kristensen P.S. & N. J. Pihl.1998. Blåmuslingebestanden i det danske Vadehav efteråret 1997. (The common mussel stock in the Danish Wadden Sea autumn 1997). DFU-report nr. 36-97. pp. 27.

Kristensen P.S. & N. J. Pihl. 2001. Blåmuslingebestanden i det danske Vadehav efteråret 2000. (The common mussel stock in the Danish Wadden Sea autumn 2000). DFU-report nr. 87-01. pp. 23.

Kristensen P.S. 2001. Blåmuslinger (Mytilus edulis L.) i det nordlige Bælthav i 1996 (fiskerizone 30, 31 og 34). Forekomster og fiskeri. (Mussels (Mytilus edulis L.) in the Northern Belt Sea (Fishing zones 30, 31 and 34). Stocks and fishery) DFU-rapport nr. 92-01. pp 59.

Kristensen P.S. 2002. Blåmuslinger (Mytilus edulis L.) i Lillebælt i 1995 (fiskerizone 40 – 44). Forekomster og fiskeri. (Mussels (Mytilus edulis L.) in Little Belt in 1995 (Fishing zones 40 - 44). Stock and fishery) DFU-rapport nr. 101-02. pp 75.

Kristensen P.S. & N. J. Pihl. 2003. Blåmuslingebestanden i det danske Vadehav efteråret 2002. (The common mussel stock in the Danish Wadden Sea autumn 2002). DFU-rapport nr. 122-03. pp. 23.

Kristensen P.S. 2003. Blåmuslinger (Mytilus edulis L.) i Århus Bugt 2002. Forekomster og fiskeri. (fiskerizone 24, 25, 26, 30, 31 og 34). (Mussels (Mytilus edulis L.) in Århus Bight. Stock and fishery. (Fishing zones 24, 25, 26, 30, 31 and 34). DFU-rapport nr. 92-01. pp 56.

Kristensen P.S., N. J. Pihl & R. Borgstrøm. 2005. Blåmuslingebestanden i det danske Vadehav efteråret 2004. (The common mussel stock in the Danish Wadden Sea autumn 2004). DFU-report nr. 141-05. pp. 23.

Kristensen P.S. & E. Hoffmann. 2004. Bestanden af blåmuslinger i Limfjorden 1993 til 2003. (The stock of mussels in Limfjorden 1993 to 2003). DFU-rapport nr. 130 – 04. pp 41.

Kristensen, P.S. & K. Laursen. The common mussel (Mytilus edulis L.) in the Danish Wadden Sea; biomass, distribution, fishery and importance as food for different bird species. - Ecology and Society. Submitted.

Laursen K. & P. S. Kristensen. Density dependent relationships between blue mussels Mytilus edulis, Eiders Somateria mollissima and Oystercatchers Haematopus ostralegus in the Danish Wadden Sea. Ecology and Society. Submitted.

Marencic, H., 2001. TMAP Blue Mussel Workshop, Tönning 11-12 October 2000. pp 35.

Munch-Petersen S. & P.S. Kristensen. 1987. Assessment of the stocks of Mussels in the Danish Wadden Sea. ICES K: 13. ICES Shellfish committee. pp. 22.

Munch-Petersen S. & P.S. Kristensen. 1989. On the applicability of aerial survey techniques for recording and estimating densities of mussel beds. ICES C.M. 1989. K 24. Pp. 16.

Munch-Petersen S. & P.S. Kristensen. 2001. On the dynamics of the stocks of blue mussels (Mytilus edulis L.) in The Danish Wadden Sea. Hydrobiologia 465: 31-43.

Nehls, G. 1995. Strategien der Ernährung und ihre Bedeutung für Energiehaushalt und Ökologie der Eiderente (Somateria mollissima (L., 1758). – Dissertation, University of Kiel. FTZ-Report Nr. 10, 1-176.

Nehls, G., I. Hertzler , C. Ketzenberg & G. Scheiffarth. 1997. Stable Mussel Beds as a Resource for Birds. – In: C. Gätje & K. Reise (eds.): The Wadden Sea Ecosystem: Exchange, Transport and Transformation Processes. Springer-Verlag, Heidelberg, Berlin. pp. 421-435.

Nehls G., G. Scheiffarth & G. Sach. 2000. Miesmuschelmonitering im Nationalpark Schleswig-Holsteinisches Wattenmeer 1999. Ein Projekt im Rahmen des Trilateral Monitering und Assessment Program (TMAP). Nationalpark Schleswig-Holsteinisches Wattenmeer. pp 58.

Nehls G., S. Gettner, G. Sach & C-P Günther. 2001. Miesmuschelmonitering im Nationalpark

Schleswig-Holsteinisches Wattenmeer 2000. Ein Projekt im Rahmen des Trilateral Monite-ring und Assessment Program (TMAP). Natio-nalpark Schleswig-Holsteinisches Watten-meer. pp 55.

Nehls G. & M. Ruth. 2004. Miesmuschelmonite-ring und Miesmuschelmanagement im Natio-nalpark Schleswig-Holsteinsches Wattenmeer. Berichts-zeitraum 1997 – 2002. Report for Natio-nalpark Schleswig-Holsteinisches Wattenmeer. pp 66.

Pihl N. J. & P.S. Kristensen.1997. Blåmuslinge-bestanden i det danske Vadehav efteråret 1998. (The common mussel stock in the Danish Wad-den Sea autumn 1997). DFU-report nr. 49-98. pp. 23.

Seamann M.N.L. & M. Ruth. 1997. The Molluscan Fisheries of Germany. In: C. L. Mackenzie, Jr., V. G. Burrel, Jr., A. Rosenfield, and W. L. Hobart (eds.), The history, present condition, and future of the molluscan fisheries of North and Central America and Europe. U.S. Dep. Commer., NOAA Tech. Rep. 129, p. 57 - 84.

Speakman J.R. 1987. Apparent absorption efficien-cies for Redshank (Tringa totanus L.) and Oys-tercatcher (Haematopus ostralegus L.): implica-tions for the predictions of optimal foraging models. Am. Nat. 130: 677-691.

Stoddard P. 2003. Reconstruction of Blue Mussel Beds Using Aerial Photographs from 1989 and 2002 of the North Frisian Wadden Sea, Germany. Report to the Nationalpark Schleswig-Holsteinisches Wattenmeer. In co-operation with Jugend für Europa. pp 70.

Zwarts L. & A-M Blomert. 1996. Daily metabolized energy consumption of Oystercatchers Haema-topus ostralegus feeding on larvae of the crane fly Tipula paludosa. Ardea 84A: 221-228.

Zwarts L., Ens B.J., J.D. Goss-Custard, J.B. Hulscher & S.E.A.L.D. Durell. 1996a. Causes of variation in prey profitability and its consequences for the intake rate of the Oystercatcher Haematopus os-tralegus. Ardea 84A: 229-268.

Zwarts L., B.J. Ens, J.D. Goss-Custard, J.B. Hulscher & M. Kersten. 1996b. Why Oystercatchers Hae-matopus ostralegus cannot meet their daily en-ergy requirements in a single low water period. Ardea 84A: 269-290.

Zwarts L., J.B.Hulscher, K. Koopman, T. Piersma & P.M. Zegers. 1996c. Seasonal and annual varia-tion in body weight, nutrient stores and mortal-ity of oystercatchers Haematopus ostralegus. Ardea 84A: 327-356.

Foreland development along the Advanced Seawall at Højer, the Danish Wadden Sea

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Vestergaard, P. 2006: Foreland development along the Advanced Seawall at Højer, the Danish Wadden Sea. In: Monitoring and Assessment in the Wadden Sea. Proceedings from the 11. Scientific Wadden Sea Symposium, Esbjerg, Denmark, 4.-8. April, 2005 (Laursen, K. Ed.). NERI Technical Report No. 573, pp. 123-132.

As part of the advanced seawall at Højer, built in 1979-1981, a marsh foreland, 150 m wide and sloping from +2.45 m DNN to +0.20-0.30 m DNN, was designed. The aim was to provide protection of the seawall and to create a green environment as a replacement of the salt marsh areas, which would be lost between this and the old seawall. The foreland was founded by marine sand, and the innermost part was sown with grasses. To enhance sedimentation, a coherent row of sedimentation fields was established along the foreland in 1986-1988. The development of the foreland has been monitored with irregular intervals since 1981. In this paper I present observations of changes in profile and vegetation, and I compare the state of the foreland in 2004 with mature marsh forelands.

The main trends observed so far have been: 1) the species richness of vascular plants has increased, 2) Glasswort *(Salicornia)* and Common Cord-Grass *(Spartina)* have established widely on tidal flats in the sedimentation fields, 3) At the inner part of the tidal flat a Common Salt-Marsh-Grass *(Puccinellia maritima)* salt marsh has gradually established, 4) the foreland landwards to the tidal flat has currently been narrowed by erosion, but has also been influenced by sand accretion, 5) the vegetation of the outer part of the foreland is still open and characterized by beach and dune species, 6) the vegetation of the inner part of the foreland is slowly developing towards a typical Wadden Sea high marsh.

In conclusion, the planned foreland has not yet been achieved after 23 years, and the development of the foreland has differed somewhat from what was originally expected. This is probably caused by the circumstance that the advanced seawall was built on a relatively low-lying tidal flat. The vegetation zonation developed so far indicates, however, that a typical marsh foreland may be formed along the advanced seawall during the coming decades on the basis of the technical support carried out until now and a continuation of the current management of the foreland. Establishment of extra brushwood groynes in the existing sedimentation fields may, however, speed up the marsh formation.

Key words: Foreland, geomorphology, management, monitoring, salt marsh, tidal flat, vegetation

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Introduction

After several flood incidents in 1976, the Danish Government decided in 1977 to protect the existing coastline at the old Højer seawall behind a new, advanced, 8.6 km long seawall starting from the Danish-German border in the south to Emmerlev in the north. As a part of the seawall, it was decided to create a green, 150 m broad foreland like the marsh forelands, which typically are developed elsewhere in the Wadden Sea (e.g. Raabe 1981). The aim of this foreland should be partly to protect the new seawall, partly to replace the former marsh foreland, the Ny Frederikskog Forland, which would be lost behind the advanced seawall. The advanced seawall and foreland were built in 1979-1981. Behind the seawall, a saltwater lake was established in the Margrethekog, (Fig. 1).

In 1979, the Danish Scientific Research Council initiated a project, aiming to monitor the vegetational development of the new foreland. The project was carried out in 1981-2004. The investigation has included the total foreland, but since 1989 especially the foreland north of the Vidå Sluice has been in focus.

The objectives of the present paper have been, based on results from the northern part of the foreland, to discuss the development up to now of the morphology and vegetation of the foreland, partly in relation to the original foreland design, partly in relation to typical, mature marsh forelands elsewhere at the Wadden Sea.

The foreland: construction and management

According to the project plan, the foreland was founded by marine sand and established with a gently sloping surface from the original tidal flat level at +0.20-0.30 m DNN (Danish Ordnance Datum) to the dike at +2.45 m DNN (Fig. 2). The sand was supplied from a pit on the tidal flat, parallel to the dike in a distance of 800 m. In order to create the basis of a coherent plant cover, the innermost 50 m of the foreland in 1980 and 1981 was fertilized and sown with a mixture of grasses: Red Fescue *(Festuca rubra)* 68%, Tall Fescue *(F. arundinacea)* 8%, Sheep's Fescue *(F. ovina)* 12% and Italian Rye-grass *(Lolium multiflorum)* 12%. Due to erosion and sand accretion in the following winters, it was necessary to supply the sowing in 1982 and 1983. Since 1981, the current management of the foreland has included seaward bulldozing of sand, accreted during winter, additional grass sowing until 1992, grazing by sheep (at the northern part of the foreland until 1990) and occasional mowing (Svend Petersen and Aksel Pedersen, pers. comm., Vestergaard 1997).

In order to enhance sedimentation on the tidal flat and thereby to enhance stabilisation of the foreland, a coherent row of sedimentation fields, about 200 x 200 m, was established in 1986-1988 (Fig. 3). After the establishment, the sedimentation fields were ditched (Danish: *grøblet*) for several years in order to drain and thereby to improve conditions for terrestrial vegetation to establish.

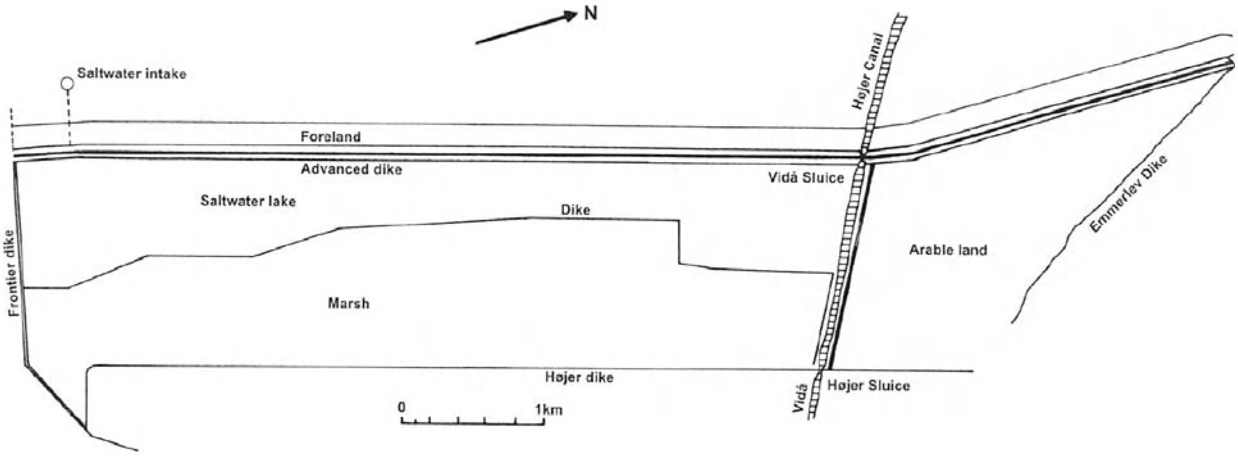

Figure 1. The Margrethekog wit h the advanced seawall and foreland. After Vestergaard 1984.

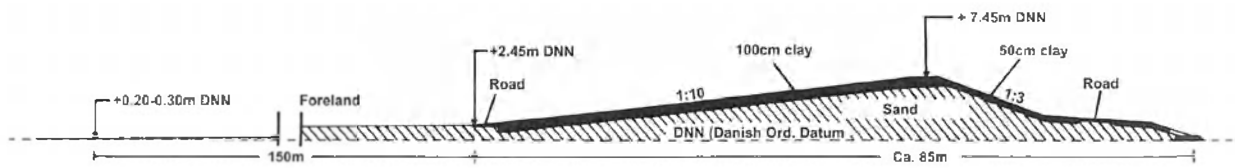

Figure 2. Schematic cross-section of the advanced seawall with the planned, 150 m broad foreland. After Jespersen & Rasmussen (1984).

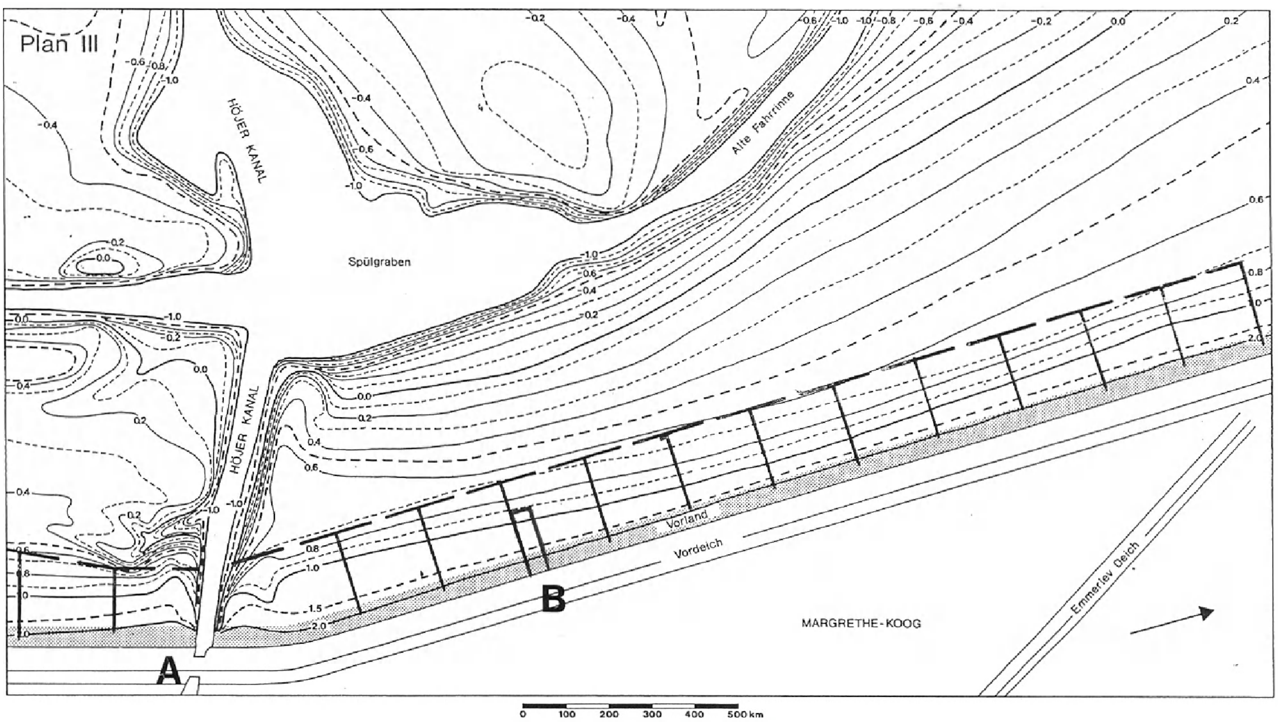

Figure 3. Contour map of the tidal flat and foreland north of the Vidå Sluice 1983/1984, with the sedimentation fields, established in 1988, inserted. A: The Vidå Sluice. B: Permanent study area used in the present study. After Jespersen & Rasmussen 1989.

Methods

The botanical investigations in the northern part of the foreland, 2.5 km, cover the period 1981-2004 with irregular intervals. Based on the morphology, the elevation above DNN and the character of the plant cover, the foreland was divided into coast-parallel zones, A, B, C, D, D´, explained in Figure 5. The width of the individual zones varied from year to year. In each zone vascular plant species were recorded (nomenclature according to Hansen 1981), and their abundance were estimated, using a 1-3 abundance scale: 1: scattered, 2: common, 3: very common to dominating.

About 800 m north of the Vidå Sluice, a representative, permanent study area, 50 x 120 m, was established (Fig. 3). Each monitoring year, the structure of the study area was mapped, based on the above-mentioned coast-parallel zones. In each zone vascular plant species were recorded, and the total plant cover was estimated. A fixed transect line, perpendicular to the dike line, was levelled for every 5th m in relation to the elevation of the road at the base of the seawall (Fig. 2). The levelling data were expressed in relation to DNN.

In this paper, I present the main trends in the development of morphology and vegetation of the foreland, based on results from selected years.

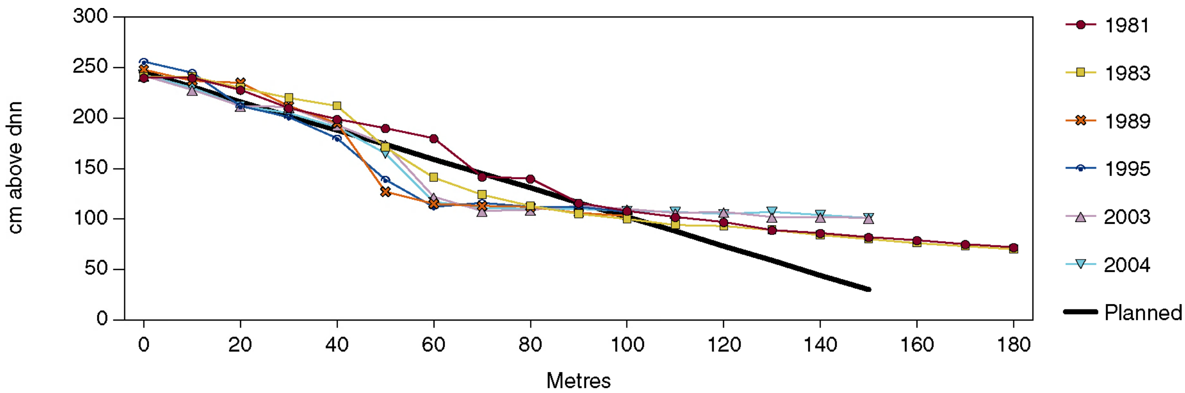

Figure 4. Change in profile of foreland and tidal flat 1981-2004, levelled along a transect line, seaward from the dike (0 m), in the permanent study area. The originally planned profile is also shown.

Results

The permanent study area: changes in profile

When compared with the planned profile, the morphology of the study area was strongly modified during the study period due to varying spatial and temporal influence of erosion, accretion and sedimentation processes (Fig. 4). Already in 1981, the study area could be divided into an upper, terrestrial *foreland* from 0-80 m, with a slope not very different from the planned slope, and a *tidal flat* below +1.40 m DNN. Apart from the innermost rather steep 10 m, the slope of the tidal flat was less steep than the planned slope. This main structure was largely retained throughout the study period, and so was the +1.40 m DNN level as being the vertical limit between foreland and tidal flat. But due to erosion, the inner border of the tidal flat gradually mowed landwards at the expense of the foreland.

Since the establishment of the sedimentation fields in 1988, the level of the tidal flat has raised several decimetres, and the width of the foreland has been rather constant, i.e. about 50 m, which corresponds to the initial grass sowing area. The micro relief of the foreland has, however, varied from year to year due to accretion of sand during winter storms, and subsequent seaward bulldozing of the sand. This has inhibited the establishment of a coherent, permanent plant cover, especially in the outer part of the foreland.

The permanent study area: changes in plant cover

The development of plant cover in the study area has reflected the changing profile and surface morphology. On the foreland, two parts could be defined: An inner, more stable part (zone A) with a more or less coherent plant cover, and an outer, less stable part (zone B+C), with a scattered plant cover.

In 1981, the plant cover at the inner part of the foreland was dominated by two of the sown species, Red Fescue and Italian Rye-grass, but included also scattered individuals of a few halophytic species, e.g. Halberd-leaved Orache *(Atriplex prostrata)*, Glasswort *(Salicornia* sp.*)* and Sea Spurrey *(Spergularia salina)*. During the following years this zone gradually narrowed (Fig. 5), and the species composition changed. In 1989, the number of species had increased to 19 with Red Fescue and Tall Fescue as dominants. In 2004, zone A was restricted to a strip, less than ten metres broad, between the road and a low bank of sand.

In 1981 the outer part of the foreland stretched from 50 to 80 m. The plant cover consisted of scattered individuals of halophytes. In 1989, this part of the foreland was replaced by tidal flat, and the seaward part of the former zone A had changed into outer foreland, zone B+C with a sparse plant cover. In 2004, the number of species in this zone had increased to 33 species, of which especially beach and sand dune species dominated.

On the tidal flat, the landward expansion and gradual raise of the level was accompanied by strongly increasing abundance of Glasswort and Common Cord-Grass *(Spartina anglica)*, especially after the establishment of the sedimentation fields. On the inner part of the tidal flat also Common Salt-Marsh-Grass *(Puccinellia maritima)* and Sea Aster *(Aster tripolium)* expanded down to about +1.10 m DNN.

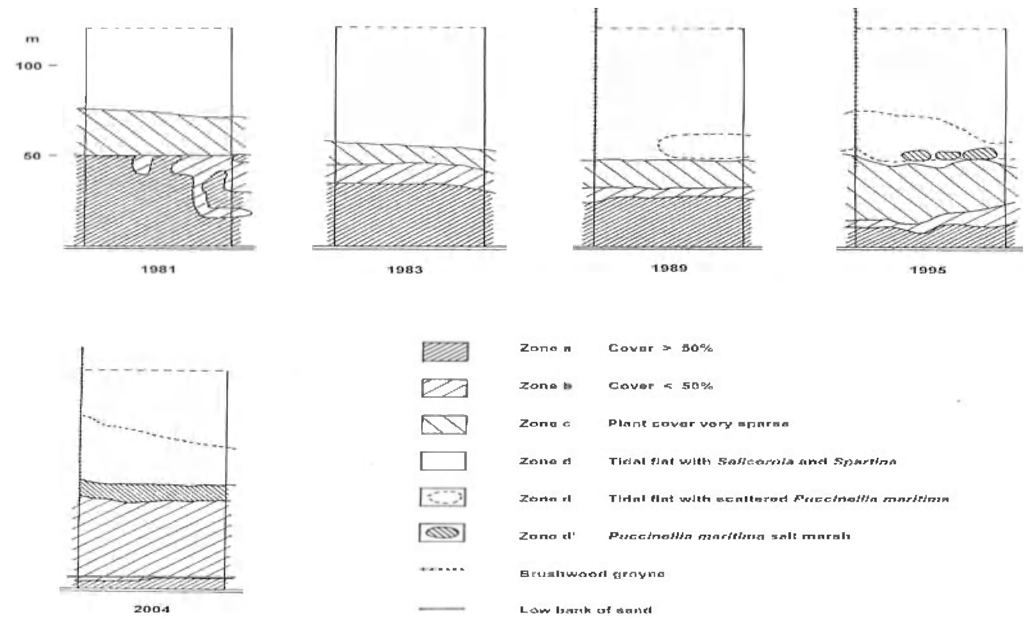

Figure 5. Change in vegetation zones in the permanent study area 1981-2004.

In 1995, scattered "islands" of Common Salt-Marsh-Grass marsh had developed on the innermost 10 m of the tidal flat within the vertical interval of about +1.15-1.40 m DNN (Fig. 6). In 2004 this belt had closed into a coherent salt-marsh community.

Figure 6. Salt marsh (Common Salt-Marsh-Grass, *(Puccinellia maritima)* developing on the inner part of the tidal flat in the permanent study area in 1995.

Changes in species richness and species abundance in foreland and tidal flat

The structure and vegetation of the entire foreland and tidal flat north of the Vidå Sluice largely repeat the structure of the permanent study area. Theoretically, only the four sown grass species were present on the foreland in 1980. The species richness increased, however, very fast (Fig. 7). Already in 1981, the number of species had increased to 33, and in 1995, to 73. The increase in number of species was mostly due to species that immigrated into the foreland. About half of these species are exclusively found in coastal habitats. The remaining species are mostly from arable land and other open inland habitats.

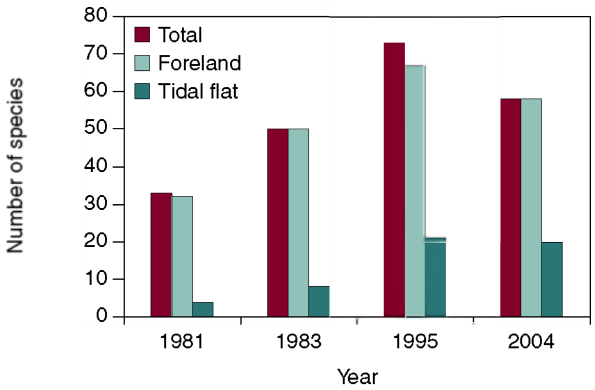

Figure 7. Change in species richness of foreland, tidal flat incl. the salt marsh, and in total, 1981-2004.

In the tidal flat, the increase in species number was mostly due to species, inhabiting the Common Salt-Marsh-Grass salt-marsh belt that gradually developed in the inner part.

The relative proportions of high and low abundance species changed over time (Fig. 8).

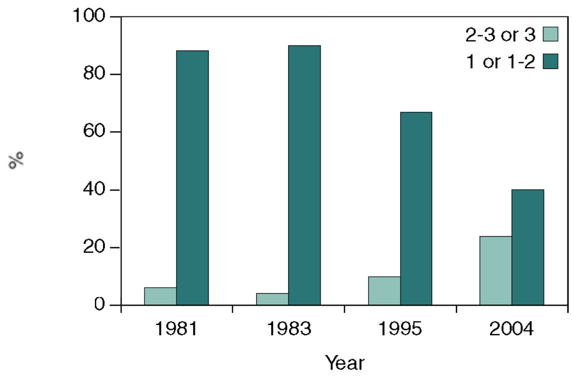

Figure 8. Changes in the proportion of high abundance species (abundance 2-3 or 3) and low abundance species (abundance 1 or 1-2) on foreland and tidal flat incl. salt marsh, 1981-2004.

In the first years after the establishment of the foreland, only the sown grass species were high-abundant (Table 1).

Table 1. Species with high abundance (2-3 or 3) in one or several zones in different years.

		1981	1983	1995	2004
Red Fescue	*Festuca rubra*	x	x		x
Italian Rye-grass	*Lolium multiflorum*	x	x		
Tall Fescue	*Festuca arundinacea*			x	
Saltmarsh Rush	*Juncus gerardi*			x	
Creeping Bent	*Agrostis stolonifera*			x	x
Sea Couch x Couch	*Elytrigia pungens x repens*			x	x
Spiny Rest-Harrow	*Ononis spinosa*			x	x
Silverweed	*Potentilla anserina*			x	x
Common Salt-Marsh-Grass	*Puccinellia maritima*			x	x
Strawberry Clover	*Trifolium fragiferum*			x	x
Sea Aster	*Aster tripolium*				x
Hybrid Sea-Couch	*Elytrigia junceiforme x pungens*				x
Couch	*Elytrigia repens*				x
Perennial Rye-grass	*Lolium perenne*				x
Black Medick	*Medicago lupulina*				x
Glasswort	*Salicornia* sp.				x
Common Cord-Grass	*Spartina anglica*				x
White Clover	*Trifolium repens*				x

The non-sown species were dependent on accidental dispersal from the surroundings. A large majority of these species occurred very scattered and largely independent of the environment. In course of the development, however, the abundance of an increasing proportion of the species increased due to generative and vegetative, internal dispersal and formation of stands in specific environments. This indicates an increasing competition between the species and an incipient formation of plant communities.

Vegetation zonation in foreland and tidal flat in 2004

In 2004, a zonation with four zones had developed: 1. Tidal flat, 2. Salt marsh, 3. Outer part of foreland, 4. Inner part of foreland (Table 2).

The tidal flat, below about +1.15 m DNN, was especially characterized by Glasswort and Common Cord-Grass, which were present everywhere in the sedimentation fields, Cord-Grass mostly forming smaller and larger clones.

In the salt marsh belt, about +1.15-1.40 m DNN, twenty species were present. Besides Common Salt-Marsh-Grass, also Sea Aster and Red Fescue could dominate (Table 2), and from 1995, Sea Purslane *(Halimione portulacoides = Atriplex portulacoides)* was present. Towards the northern part of the foreland, where the seawall approaches the old coastline, also Sea Club-Rush *(Scirpus maritimus)* and Common Reed *(Phragmites australis)* were abundant, probably due to fresh water influence. The surface of the salt marsh areas was about 20-30 cm above the surrounding sand flat, and the uppermost 5-10 cm of the sandy soil contained some organic matter (2-4%) (Vestergaard 1997), probably originating from sedimentation at high tide.

Table 2. Species composition in yr 2004 of tidal flat, salt marsh belt, outer and inner foreland.
Abundance scale: x: scattered; xx: common; xxx: very common-dominating.

		Tidal flat	Salt marsh	Outer foreland	Inner foreland
Yarrow	*Achillea millefolium*			x	xx
Creeping Bent	*Agrostis stolonifera*		xx	xxx	xxx
Sea Wormwood	*Artemisia maritima*			x	
Mugwort	*A. vulgaris*			xx	x
Sea Aster	*Aster tripolium*	x	xx	x	x
Grass-leaved Orache	*Atriplex littoralis*			xx	
Halberd-leaved Orache	*A. prostrata*		x	xx	x
Sea Rocket	*Cakile maritima*			x	
Saltmarsh Serge	*Carex extensa*		x		
Little Mouse-ear	*Cerastium semidecandrum*				x
Creeping Thistle	*Cirsium arvense*			xx	xx
Wild Carrot	*Daucus carota*			x	
Sand Couch	*Elytrigia junceiforme*			xx	
Hybrid Sea-Couch	*E. junceiforme x pungens*			xxx	
Sea Couch	*E. pungens*			x	xx
Sea Couch x Couch	*E. pungens x repens*		x	xxx	xx
Couch	*E. repens*			xx	xxx
Tall Fescue	*Festuca arundinacea*			xx	x
Red Fescue	*F. rubra*		xx	xxx	xxx
Sea Milkwort	*Glaux maritima*		xx	x	
Sea Purslane	*Halimione portulacoides*		x	x	
Sea Sandwort	*Honckenya peploides*			xx	x
Saltmarsh Rush	*Juncus gerardi*		xx		x
Sea Pea	*Lathyrus japonicus*			x	
Autumn Hawkbit	*Leontodon autumnalis*			x	xx
Lyme Grass	*Leymus arenarius*			x	x
Common Toadflax	*Linaria vulgaris*			x	x
Perennial Ryegrass	*Lolium perenne*				xxx
Common Birdsfoot Trefoil	*Lotus corniculatus*			xx	xx
Black Medick	*Medicago lupulina*			xx	xxx
Red Bartsia	*Odontites verna*				xx
Spiny Rest-Harrow	*Ononis spinosa*			xx	xx
Common Reed	*Phragmites australis*		x	x	
Buckshorn Plantain	*Plantago coronopus*				xx
Ribwort Plantain	*P. lanceolata*			x	xx
Ratstail Plantain	*P. major*			x	xx
Sea Plantain	*P. maritima*		xx	xx	xx
Annual Meadow-Grass	*Poa annua*				x

Table is continued on next page

		Tidal flat	Salt marsh	Outer foreland	Inner foreland
Smooth Meadow-Grass	*P. pratensis*				x
Knotgrass	*Polygonum aviculare*			x	xx
Silverweed	*Potentilla anserina*			xx	xxx
Common Salt-Marsh-Grass	*Puccinellia maritima*	x	xxx	x	
Curled Dock	*Rumex crispus*			xx	
Knotted Pearlwort	*Sagina nodosa*				xx
Glasswort	*Salicornia sp.*	xxx	xx		
Sticky Groundsel	*Senecio viscosus*			x	
Groundsel	*S. vulgaris*			x	x
Sea Club-Rush	*Scirpus maritimus*		xx	x	x
Bladder Campion	*Silene cucubalus*			x	x
Corn Sow-Thistle	*Sonchus arvensis*			xx	xx
Sea Spurrey	*Spergularia marina*	x	x	x	
Greater Sea Spurrey	*S. media*		xx		
Common Seablite	*Suaeda maritima*		xx	x	
Tansy	*Tanacetum vulgare*			xx	x
Dandelion	*Taraxacum sp.*			xx	x
Strawberry Clover	*Trifolium fragiferum*		x	xx	xxx
Red Clover	*T. pratense*			x	x
White Clover	*T. repens*			xx	xxx
Sea Arrow-Grass	*Triglochin maritimum*		xx		
Scentless Mayweed	*Tripleurospermum inodorum*			x	x
Coltsfoot	*Tussilago farfara*			x	x
Tufted Vetch	*Vicia cracca*			x	x

At the foreland, between +1.40 and +2.45 m DNN, the development of vegetation has been less directional than in the lower zones. In the outer part, 50 species were present in 2004. The total cover was mostly low, < 50%, and the sand surface was instable. The dominants were Creeping Bent *(Agrostis stolonifera)*, Red Fescue, Sea Couch x Couch *(Elytrigia pungens x repens)* and Hybrid Sea-Couch *(E. junceiforme x pungens)*, of which especially the latter formed coherent, high swards over large areas (Fig. 9). The other species were beach and sand dune species, salt marsh species and species from dry inland habitats.

In the inner part of the foreland the plant cover was somewhat more stable and coherent, but the sandy soil was still very low in organic matter. The number of species was 43. The vegetation was dominated by more or less salt-tolerant grasses: Creeping Bent, Couch *(Elytrigia repens)*, Red Fescue, and Perennial Rye Grass *(Lolium perenne)*, but also other grasses and a couple of dicotyledons were important (Table 2).

Figure 9. Dominance of Hybrid Sea-Couch *(Elytrigia junceiforme x pungens)* in the outer part of the foreland in 2004.

Discussion and conclusion

One of the intentions of the planners of the advanced seawall was to create a 150 m green foreland in front of it. However, profile as well as vegetation of the foreland has shown a development, which differs from that expected. This is probably because the advanced dike was built on a relatively low-lying tidal flat, as pointed at by Jespersen & Rasmussen (1989). This caused already from the very beginning a strong modification of the foreland profile by erosion and accretion of sand during winter, as also observed by Jespersen & Rasmussen (1984, 1989) on the basis of levelling in 1982 and 1983 of 15 foreland profiles.

But never-the-less many traits indicate, that the development of the foreland at Højer largely follows the same direction as known from tidal flats and salt marshes elsewhere in the Wadden Sea (e.g. Jakobsen 1964, Veenstra 1980, Raabe 1981).

The lower limit of the foreland was planned at a level of +0.20-0.30 m DNN, corresponding to a distance of 150 m from the dike. However, the actual level at 150 m, measured in 1981-1983, was much higher, about +0.80 m DNN (Fig. 4, and Jespersen & Rasmussen 1984). Thorough studies by Jakobsen (1964) from the Danish Wadden Sea have shown that the tidal flat community with Glasswort *(Salicornia)* develops within the vertical interval between the mean high water level (MHW) and 20-30 cm below that level. According to calculations by Vestergaard (1984), on the basis of sea-level fluctuation data from the Vidå Sluice 1982 and 1983, the MHW level at Højer is about +1.15m DNN. It should therefore be expected, that Glasswort would invade the tidal flat from about +0.90 m DNN. And this was in fact observed already during the first years. Also according to Jakobsen (1964), salt marsh development, based on Common Salt-Marsh-Grass *(Puccinellia maritima)*, is stabilizing at about MWH. This was confirmed by the results from the Højer foreland as well, which showed that the initial marsh belt developed from +1.15 m DNN.

The colonisation of Glasswort (and Common Cord-Grass, *Spartina*) on the tidal flat proceeded very slowly during the first years of the study period. This may be ascribed to low sedimentation rate, which again may be due to partly the presence of the deep sand pit on the tidal flat 800 m from the dike, and partly to the lack of sedimentation fields until 1988. After 1988, the colonisation of Glasswort and Common Cord-Grass on the tidal flat increased, apparently due to increasing sedimentation caused by the sedimentation fields, but probably also because of gradual filling-up of the sand pit, allowing material to be sedimented on the tidal flat, which was earlier sedimented in the sand pit. So, according to measurements by Jespersen & Rasmussen (1989), the water depth in the sand pit declined from 1982 to 1989, and in 2004 the sand pit seems to be completely filled by sediment (Svend Petersen, pers. comm.).

The development up to now as well as the possible future vegetation development of the foreland at Højer, can be judged by comparing the zonation observed with salt marsh zonation studied elsewhere in the Wadden Sea. According to Joenje et al. (1976), Raabe (1981), Pedersen (1983) and Dijkema (1983), the vegetation zonation on the mostly grazed salt marshes at the Wadden Sea generally includes four vertical zones: Tidal flat with Glasswort and Common Cord-Grass; a low marsh, from about the MHW level, dominated by Common Salt-Marsh-Grass; a middle marsh, from about 30 cm above the MHW level, dominated by Red Fescue *(Festuca rubra)*, Saltmarsh Rush *(Juncus gerardi)*, Thrift *(Armeria maritima)*, Creeping Bent *(Agrostis stolonifera)*, Sea Milkwort *(Glaux maritima)* and Sea Wormwood *(Artemisia maritima)*, and a high marsh, dominated by Red Fescue, Perennial Ryegrass *(Lolium perenne)*, White Clover *(Trifolium repens)*, Tall Fescue *(Festuca arundinacea)* and Spiny Rest-Harrow *(Ononis spinosa)*.

This zonal structure is also valid for ungrazed marshes, but here Sea Purslane *(Halimione portulacoides)* is often dominant in the lower marsh, and Sea Couch *(Elytrigia pungens)* and Couch *(E. repens)* in the higher marsh (Esselink 2000, Bakker et al. 2003).

At Højer, development of three of these zones is indicated by the observations so far. The vegetation on the tidal flat is well developed. A low marsh, i.e. the Common Salt-Marsh-Grass belt, is developing; most of the typical species are present, but the area is still small. Also a high marsh is developing in the inner foreland. The above-mentioned typical species are present, but the plant cover is not coherent, the content of organic matter in the soil is low, and the species composition varies rather much, even within small distances. The relative recent appearance of Sea Purslane in the low marsh, and the role of Couch and Sea Couch in the high marsh agrees well with the, at least since 1990, ungrazed state of the foreland.

A middle marsh is, however, not yet present at the Højer foreland. Even if many of the typical middle marsh species are present, the strong dominance of Hybrid Sea-Couch *(Elytrigia junceiforme x pungens)* (Fig. 9) and the presence of sandy beach and sand dune species indicate a still very unstable environment, characterized by mobile sand. At the foreland south of the Vidå Sluice trials with artificial establishment of Common Salt-Marsh-Grass sward were carried out in 1986-1988 at the vertical level +1.70-1.80 m DNN (Jespersen & Rasmussen 1989), i.e. at a higher level than that occupied by the spontaneously developed Common Salt-Marsh-

Grass belt. Probably due to erosion, sand coverage and drought these swards, however, largely had disappeared in 1994 (Vestergaard 1997).

In conclusion, the planned marsh foreland has not yet been achieved after 23 years, and the development has until now differed from the originally expected. The development of vegetation zonation so far indicates, however, that a typical marsh foreland may be formed along the advanced seawall during the coming decades. A factor, which may delay this development, is that the accretion of sand on the foreland still demands measures like bulldozing. Reduction of this negative factor awaits the formation of a broader, protecting Common Salt-Marsh-Grass salt marsh belt in front of the foreland. To speed up this process, an increasing sedimentation rate, which probably can be achieved by establishment of extra, coast-parallel brushwood groynes in the existing sedimentation fields, would be positive.

The monitoring method used in this study, which combines a reiterate survey of a larger area on the basis of functional, non-fixed zones, and a more intensive reiterate study and mapping of a representative study area, large enough to include most of the variation in the larger area, seems to be a suitable and not very expensive method for long-term monitoring of an extensive coastal area.

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References

Bakker, J.P., Bos, D. & de Vries, Y. 2003: To graze or not to graze: that is the question. – In: Wolff, W.J., Essink, K., Kellermann, A. & van Leeuwe, M.A. (Eds.); Challenges to the Wadden Sea area. Proceedings of the 10th international scientific Wadden Sea symposium, Groningen, The Netherlands, 31 October – 3 November 2000, pp. 67-87.

Dijkema, K.S. 1983: The salt-marsh vegetation of the mainland coast, estuaries and halligen. - In: Dijkema, K.S. & Wolff, W.J. (Eds.); Flora and vegetation of the Wadden Sea islands and coastal areas. Report 9. Leiden, pp. 185-220.

Esselink, P. 2000. Nature management of coastal salt marshes. Interactions between anthropogenic influences and natural dynamics. – Ph.D. thesis, University of Groningen. 253 pp.

Hansen, K. 1981: Dansk Feltflora. – Gyldendal, København, 757 pp.

Jakobsen, B. 1964: Vadehavets morfologi. En geografisk analyse af vadelandskabets formudvikling med særlig hensyntagen til Juvre Dybs tidevandsområde (In Danish with English summary: The morphology of the Wadden Sea. A geographical analysis of the morphological development of the tidal flat landscapes with special reference to the Juvre Dyb tidal area). - Folia Geographica Danica 11, 1: 1-176.

Jespersen, M. & Rasmussen, E. 1984: Forlandet ved det fremskudte dige. - Vadehavsrapport nr. 2. Geografisk Institut, Københavns Universitet.

Jespersen, M. & Rasmussen, E. 1989: Margrethe-Koog. Landgewinnung und Küstenschutz im südlichen Teil des dänischen Wattenmeeres (In German with English summary: Margrethekog. Land reclamation and coastal protection in the southern part of the Danish Wadden Sea). - Die Küste. Archiv für Forschung und Technik an der Nord- und Ostsee 50: 97-154.

Joenje, W., Westhoff, V. & van der Maarel, E. 1976: Forlandsmarskens og klittens plantevækst. – In: Abrahamse, J., Joenje, W. & van Leeuwen-Selt, N. (Eds.); Vadehavet. Et dansk-tysk-hollandsk naturområde. Bygd, Esbjerg.

Pedersen, A. 1983: The vegetation of the Wadden Sea islands in Denmark and Schleswig-Holstein. - In: Dijkema, K.S. & Wolff, W.J. (Eds.); Flora and vegetation of the Wadden Sea islands and coastal areas. Report 9. Leiden, pp. 137-165.

Raabe, E.-W. 1981: Über das Vorland der östlichen Nordseeküste. – Mitteilungen der Arbeitsgemeinschaft Geobotanik in Schleswig-Holstein und Hamburg 31: 1-118 + Appendix.

Veenstra, H.J. 1980: Introduction to the geomorphology of the Wadden Sea area. - In: Dijkema, K.S., Reineck, H.-E. & Wolff, W.J. (Eds.); Geomorphology of the Wadden Sea area. Report 1. Leiden, pp. 8-19.

Vestergaard, P. 1984: Det fremskudte dige ved Højer. De første faser af vegetationens udvikling på det kunstige forland (In Danish with English summary: The initial stages of vegetational succession on an artificial dike-foreland at the Danish Wadden Sea). - Københavns Universitet, Institut for Økologisk Botanik. 66 pp.

Vestergaard, P. 1997: Vegetationens udvikling på forlandet ved det fremskudte dige ved Højer (In Danish with English summary: Development of vegetation on an artificial dike-foreland at the Danish Wadden Sea). - Flora og Fauna 103: 77-93.

Assessment of breeding birds in SPAs in Danish Wadden Sea marshland

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Laursen, K. 2006: Assessment of breeding birds in SPAs in Danish Wadden Sea marshland. In: Monitoring and Assessment in the Wadden Sea. Proceedings from the 11. Scientific Wadden Sea Symposium, Esbjerg, Denmark, 4.-8. April, 2005 (Laursen, K. Ed.). NERI Technical Report No. 573, pp. 133-141.

Six SPAs (Special Protection Areas) have been designated according to the EU-Birds Directive in the Danish Wadden Sea marshland (marshland areas separated from the Wadden Sea by a seawall). The objective is to protect wetlands of international importance, and to manage them in a way that promote their conservation status, including bird species mentioned on Annex 1 of the EU-Birds Directive (birds species that shall be protected in the EU member states). In this study the number of breeding birds has been evaluated during 1983-2001. Species considered are those that were included in the foundation description of the SPAs when they were designated. The species listed for each SPA include both species on the Annex 1 as well as additional species that contributed to describe the characteristic bird fauna of the SPA. During 1983-2001 in total 24% of the breeding bird species on Annex 1 have increased, and so did also 21% of the additional breeding bird species mentioned. However, 53% of the bird species on Annex 1 decreased in numbers together with 46% of the additional species. A national action plan has been accepted for threatened meadow birds in important grassland areas in Denmark to stop the decreasing trend and improve conditions for breeding birds. Future monitoring will reveal if this action plan had relieved the decreasing trends.

Key words: Breeding bird, EU-Bird Directive, historical data, numbers, SPA, trend

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Introduction

The Forest and Nature Agency appointed in 1983 six SPAs (Special Protection Areas) in the Danish Wadden Sea marshland according to the EU-Birds Directives. SPAs shall be designated in each EU member state in areas of international importance, and the member states are obliged to manage the areas in a way that protect or promote their conservation status. In addition the Annex 1 of the EU Birds Directives species are mentioned that are particular threatened in the member states, and the SPAs appointed shall include one or more of these species to safeguard their status.

The six SPAs in the Danish Wadden Sea marshland are (see Fig.1):

SPA no. 51: Ribe Holme and meadows along the Ribe Å and the Kongeåen (in short Ribe).
SPA no. 52: Mandø.
SPA no. 53: Fanø.
SPA no. 60: Vidåen, Tønder Marsh and the Margrethe Koog incl. Saltvandssøen (in short Tønder Marsh).
SPA no. 65: Rømø.
SPA no. 67: Ballum and Husum Enge and the Kamper Salt meadows (in short Ballum).

These SPAs are described in the books 'EF-fuglebeskyttelsesområder' (Skov- og Naturstyrelsen 1983) and 'EF-fuglebeskyttelsesområder og Ramsarområder' (Skov- og Naturstyrelsen 1995).

For each SPA a bird species list is given for species on the Annex 1 for which the area has been designated. Besides, this list also includes additional species that are particularly numerous in the area or are scarce in number in Denmark. These additional species are also mentioned for each SPA because they contribute to characterise the bird fauna in the area. Several of such species are included on the national Red List and Yellow List (Stoltze & Pihl 1998, Stoltze 1998).

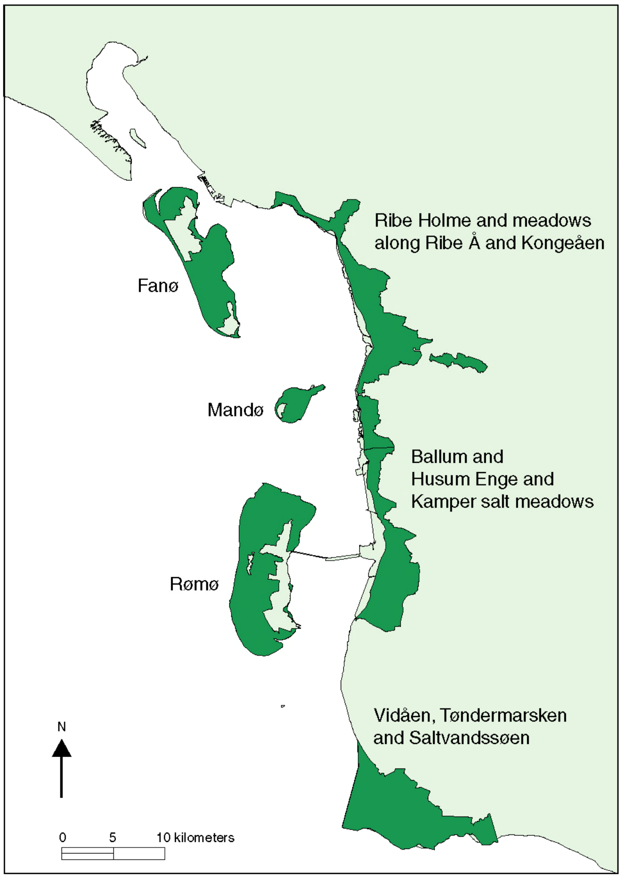

Figure1. Map showing the Danish Wadden Sea. The six marshland SPAs treated in the report are indicated.

Material and methods

The basic description of the species for which the SPAs has been designated contains information of the species number from 1983 when the SPAs were established and for the following years or periods 1987-1988 and 1993-1994 (Skov- og Naturstyrelsen 1995). For this study the breeding birds numbers are brought up to date by including the two later total counts of breeding birds in the Wadden Sea in 1996 (Rasmussen & Thorup 1998) and 2001 (Rasmussen 2003).

The information on breeding birds for the years before 1988 is based on local reports. In the years after the Trilateral Monitoring and Assessment Program (TMAP) was established, total counts of breeding birds were performed every five years in 1991, 1996 and 2001 (Rasmussen 2003). For these counts a detailed method was described (Hälterlein et al 1995).

In this paper the trend of the breeding bird is evaluated from 1983 to 2001, and grouped into the following categories: Increasing (I), stable (S), decreasing (D) or accidental (A). The latter refers to species only recorded one or two times (see below).

The survey intensity was low during the first years than later, which means that there could be more birds present during the first surveys than actually recorded. On the other hand if a species was not recorded or only recorded in small numbers during the last years, it is likely that the species had disappeared or occurring in smaller numbers than during the former period.

This raises some methodology problems that the survey intensity changed during the study period. However, histological figures can contribute to valuable information. This is a common problem and Boyd (2003) claimed that considering management aspect, 'pragmatism must take precedence over perfectionism'. In our study the material can not be treated using statistical methods due to both methodological problems and because the figures for some species are small and given with an unknown uncertainty. Due to these circumstances conclusions have not been drawn for single species, nor have any conclusions been drawn for a single SPA. Conclusions have only been drawn when more species showed the same tendency and when a tendency was seen in more SPAs.

Some species occur in small numbers as e.g. dunlin *Calidris alpina* and ruff *Philomachus pugnax*. However, these species are targets of considerable interest both due to their presence on the Annex 1 of the EU-Bird Directive and on the Danish Red List (Stoltze & Pihl 1997, Thorup 2004). Therefore it is important to include them in the analysis, and to formulate the criteria for trend evaluation in a way that minority species could be included.

The trend of the species is evaluated using the following criteria:

1) The trend is only evaluated if there are data from 4 out of the 5 years/periods and data from 2001 shall be present.

2) The trend is decreasing if a species is recorded by a + (present) or a number of pairs in the first year (or in the second year if the first year is lacking), and the species is not recorded in the following years.

3) The trend is decreasing if the number of pairs in 2001 is lower than during the former years. For species with more than 10 pairs the difference shall be >20%. However, if a species is only recorded in 2001 with one pair, the occurring species is considered as accidental.

4) The trend is increasing if the numbers of pairs in the first year or period is lower than during the following years. For species >10 pairs the difference shall be >20%.

5) The trend has changed if a species was recorded with higher or lower numbers during the 2-3 latest counts compared to the 2-3 earlier counts. For species with >10 pairs the different shall be >20%.

6) The occurrence of a species is accidental if the number is 0-1 or 0-2 pairs during the period, and a trend was not evaluated.

The trilateral monitoring program does not cover all species mentioned in the designation criteria of the SPAs, e.g. bittern *Botaurus stellaris*, marsh harrier *Circus aeruginosus* and pigeons, owls and passerines. Therefore ornithologists with local experiences have been contacted for supplementary information on these species. For further information on the methods see Laursen (2005).

Results

Results from each of the six SPAs are presented, with the species on the Annex 1 of the EU-Bird Directives mentioned first and afterwards the additional species. The number of pairs for each species is shown in Appendix 1-3 including the evaluated trend (increasing: I; constant: C; decreasing: D; and accidental: A) in the right column. The species are not commented in the text, for which an evaluation is not possible according to the criteria.

SPA no. 51: Ribe
Marsh harrier has increased in numbers (Appendix 1). The occurrence of avocet *Recurvirostra avosetta* and short-eared owl *Asio flammeus* is evaluated as constant, however, the number of ruff had decreased and it was not recorded since 1993-94. The occurrence of hen harrier *Circus cyaneus* is considered as accidental. For the additional species garganey *Anas querquedula*, shoveler *A. clypeata*, and black-tailed godwit *Limosa limosa* a reduction in numbers was observed. Gargeney and shoveler have not been recorded since 1993-94.

SPA no. 52: Mandø
Common tern *Sterna hirundo* has increased in numbers; avocet, dunlin and arctic tern *Sterna paradisaea* have been constant, while ruff has decreased in numbers and was not recorded after 1991 (Appendix 1). The occurrence of kentish plover *Charadrius alexandrinus* and little tern *Sterna albifons* is evaluated as accidental. For the additional species the trend was increasing for black-tailed godwit and constant for teal *Anas crecca* and eider duck *Somateria mollissima*.

SPA no. 53: Fanø
Bittern, marsh harrier and kentish plover have increased in numbers, while avocet and dunlin have been constant. However, montagu's harrier *Circus pygargus*, ruff, arctic tern, little tern and short-eared owl were reduced in numbers, and have not been recorded since 1983 and 1988-89 respectively (Appendix 1). Hen harrier has only bred once and its occurrence is considered as accidental. For the additional species the number of curlew *Numenius arquata* has increased, however, the number of teal, shoveler and grasshopper warbler *Locustella naevia* has decreased and these were not recorded since 1993-94.

SPA no. 60: Tønder Marsh
This area is treated as three separate areas (Magisterkogen, Ydre Koge and Margrethe Kog), because they are managed in different ways.

Magisterkogen: The number of bittern, white stork *Ciconia ciconia*, marsh harrier, montagu's harrier, spotted crake *Porzana porzana* and black tern *Chlidonias niger* has decreased (Appendix 2). The occurrence of common tern is evaluated as accidental. For the additional species the number of gadwall *Anas strepera* and pintail *Anas acuta* has increased, the trend of teal was constant, while the numbers of garganey and black-tailed godwit have decreased.

Ydre Koge: The number of bittern, marsh harrier, montagu's harrier and black tern have decreased (Appendix 2). For the additional species the number of gadwall has increased, the number of garganey, black-tailed godwit has decreased, while the occurrence of widgeon *Anas penelope* and teal is evaluated as accidental.

Margrethe Kog: The number of avocet has increased and numbers of common terns is considered as constant. However, marsh harrier, montagu's harrier, kentish plover, dunlin, arctic tern and little tern experienced decreases (Appendix 2). For the additional species the number of gadwall and black-tailed godwit has increased, the number of widgeon and pintail was constant, while the number of teal and garganey has decreased.

SPA no. 65: Rømø
The number has increased for kentish plover, arctic tern and little tern, it has been constant for avocet, while it decreased for dunlin, ruff, common tern, sandwich tern *Sterna sandvicensis* and short-eared owl (Appendix 3). For the additional species the number was stable for curlew and black-tailed godwit.

SPA no. 67: Ballum
Numbers decreased for ruff, which has not been reported since 1983 (Appendix 3). For the additional species the number was stable for lapwing *Vanellus vanellus*. However the number decreased for black-tailed godwit.

For the six SPAs taken together an evaluation of common trends was made for each species included in the Annex 1 of the EU-Bird Directive. In this trend evaluation species-specific trends for each SPA were considered and increases and decreases were weighted against each other (e.g. three areas with increases and one area with a decrease give an increase as a common trend of the species considered). The analyses of the common trend show that four species (24%) had increased in number (bittern, marsh harrier, kentish plover and common tern), three species (17%) were stable in number (white stork, water rail *Rallus aquaticus* and avocet), nine species (53%) had decreased in number (montagu's harrier, spotted crake, ruff, dunlin, arctic tern, sandwich tern, little tern, black tern and short-eared owl) and for one species (6%) the common trend was regarded accidental (hen harrier) (Fig. 2A). For the additional species there was a similar result; 21% had increased in number, 29% was stable, 36% had decreased and for 14% the trend was considered as accidental (Fig. 2B).

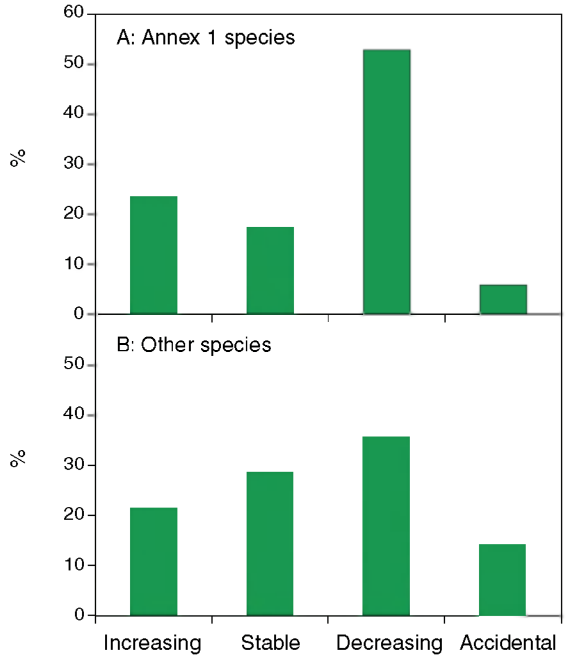

Figure 2. Trends of breeding birds (in %) in the marshland SPAs in the Danish Wadden Sea distributed in categories: Increasing, Stable, Decreasing and Accidental. A: Species on the Annex 1 of the EU-Bird Directive. B: Additional species mentioned in the appointment description of the SPAs.

However, it can be difficult to evaluate a common trend of a species, if the species has increased in two areas, has been constant in one area and has decreased in a fourth area. Therefore all trends in Appendix 1 for the two groups of species (the species in the Annex 1 of the EU-Bird Directive and the additional species, respectively) have been summed up for all areas (e.g. all evaluations of trends: I, S, D and A had been added). The summation of the trends for all Annex 1 species of the EU-Bird Directive showed that 21% of the trends were increasing, 25% of the trends were stable, 46% of the trends were decreasing and 8% was considered as accidental (Appendix 1-3). For the additional species there were increases for 17% of the trends, 30% of the trends were stable, 44% of the trends were decreasing and 9% of the trends were considered as accidental.

The results of the two calculation methods used for the Annex 1 species and the additional species respectively, show small differences. However, the results of both methods showed the same tendencies for the species.

Discussion

Trends in the International Wadden Sea

Trends of breeding birds in the International Wadden Sea have been analysed during 1991-2001 (Koffijberg et al. 2005). Nine species on the Annex 1 of the EU-Bird Directive are in common in both that report and in the present study. Three of these species were either increasing or stable in the Danish Wadden Sea marshland, and in the study covering the entire Wadden Sea two species were also stable or increasing (avocet, common tern) and one species were decreasing (kentish plover). In the Danish Wadden Sea six species were decreasing in the marshland areas, while four of these species were increasing or stable in the entire Wadden Sea (sandwich tern, arctic tern, little tern, short-eared owl) and two species were decreasing in both studies (dunlin, ruff). It is important to stress that the two studies do neither cover the same period or the same area. The study in the Danish Wadden Sea goes further back in time using historical data compared to the study covering the entire Wadden Sea. Besides, the first mentioned study focus on the marshland areas behind the seawalls, while the results from the entire Wadden Sea covers all areas including the saltmarsh areas in front of the seawalls. The results show that more species had decreased in the Danish Wadden Sea marshland than in the entire Wadden Sea.

Factors affecting breeding birds

Several factors are influencing the number of breeding birds (Koffijberg et al. 2005). Agricultural activities, including mowing and livestock-grazing are important to maintain a breeding population for several species. Experiences from several sites in Denmark (Tøndermarsh, Tipperne, Vejlerne, and Saltholm), Germany and the Netherlands have shown this (Beitema et al 1995, Nehls 1998, Rasmussen& Laursen 2000, Thorup 2004). It is also known that most of the bird species connected to meadows and marshland are depending on the intensity of the farming activity; e.g. common snipe *Gallinago gallinago* breeds in areas with a very low farming intensity, while on the other hand oystercatcher *Haematopus ostralegus* has its highest densities on more intensively used grassland (Beintema et al 1995). Lapwing is positioned in-between these two species. However, the intensity of the agricultural activity in the SPAs in the Danish Wadden Sea is not known. On the other hand analysis of aerial photographs in 1999 showed that only about 30% of the areas were permanent grassland (defined as grassland more than seven years old) in the SPA no. 51: Ribe and SPA no. 67: Ballum, while it was higher in the SPA no. 65: Rømø (53%), the SPA no. 52: Mandø (72%) and in some of the areas in the Tøndermarsh, Margrethe Kog (75%) and the Ydre Koge (85%) (Kampsax 2001).

Fields that are ploughed every year have only a small density of breeding marshland birds compared to permanent grasslands. Most meadow birds do not breed on fields ploughed every year. However, oystercatcher and to a lesser extent also lapwing may use these types of agriculture areas, but often with poor breeding results (Ettrup & Bak 1985, Falk et al. 1991). Montagu's harrier has changed breeding habitat during the last years from reed bed areas to fields with winter cereals (Ehmsen 2004). Grass areas can be re-laid (re-seeded) and studies on these new established grass areas indicate that they have a lower number of marshland birds than old grass areas (Falk et. al 1991). It lasts probably about 10-20 years before the density of breeding birds is at the same level on the two types of fields (Clausen pers. com.)

Grazing animals may destroy a large part of the meadows birds nest. On pastures with a density of three young cattle per ha, about 80% of the clutches were destroyed (Nielsen 1996). In general there is a positive relationship between the density of cattle and the destruction of nests. Likewise there is a positive relationship between the number of days with grazing cattle and the number of nests destroyed (Nielsen 1996).

Mowing can be an advantage for some of the breeding meadow birds. In mowed fields the nests are not destroyed by cattle and not otherwise disturbed before the mowing takes place. In this way the breeding success can be improved for species that prefer to breed in high vegetation (Thorup 1998). However, it is important, that most of the birds haves finished breeding (including the chick-rearing period) before mowing occurs Otherwise, nests are destroyed by mowing and chicks are killed.

Other factors that influence the breeding densities of meadow birds are ground water level during springtime and the presence of predators (Rasmussen & Laursen 2000, Kahlert et al. 2003, Olsen 2004). However, these parameters will not be considered in detail here, but studies of breeding birds in the Wadden Sea indicate that there is an increasing predator pressure on nests in the mainland areas (Koffijberg et al. 2005).

Management

The management of the SPSAs is not known. However, the proportion of permanent grassland defined as grass areas older than seven years have been mapped (Kampsax 2001). The results indicate that there is a relationship between permanent grassland and the number of breeding birds. For example the proportion of species with either a positive or stable trend is large (> 40%) in SPAs with permanent grasslands larger than 50% (e.g. Margrethe Kog, Rømø and Mandø). However, a large proportion of grasslands is obviously not the only factor to safeguard an increasing or stable trend for the species, since a large part of the species are decreasing in both Magisterkogen and Ydre Koge. Both of these SPAs have permanent grasslands covering more than 85% of the area but they show different trends in the breeding bird populations. Therefore it is likely that management of the areas plays an important role for the species trend, as shown for Margrethe Kog and Ydre Koge in the Tøndermarsh (Rasmussen & Laursen 2000). Thorup (2004) made a review on the development of breeding marshland birds in Denmark and concluded that species were only stable or increasing in areas with a management plan that include the demands of breeding marshland birds. As a follow up to that review the Forest and Nature Agency under the Ministry of Environment, have made an action plan for threatened marshland bird species. The action plan focus on 25 of the most important breeding bird areas in Denmark and describe elements in an active management for each area (Asbirk & Pitter 2005). The SPAs of the Wadden Sea areas dealt with in this paper are included in the action plan, and future monitoring results will show if the negative trend has halted for the species presented in this report.

References

Asbirk, S, & Pitter, E. 2005. Handlingsplan for truede engfugle. – miljøministeriet, Skov- og Naturstyrelsen.

Boyd, H. 2003. The need for greater use of historical population data. Wader Study Group Bull. 100: 175-177.

Beitema, A., Moedt, O. & Ellinger, D. 1995. Ecologische Atlas van de Nederlandse Weidevogels.- Instituut voor Bos- en Natuuronderzoek. Schuyt & Co.

Ehmsen, E. 2004. Hedehøg Circus pygatgus. I: Grell, M.B., Heldbreg, H., Rasmussen, b., Stabel, M. Toft, J. & Vikstrøm, T. (Red.); Truede og sjældne ynglefugle i Danmark 1998-2003.- Dansk Orn. Foren. Tidsskr. 98: 45-100.

Ettrup, H. & Bak, B. 1985. Nogle træk af danske vibers Vanallus vanellus yngleforhold. – Dansk Ornitologisk Forenings Tidsskrift 79: 43-55.

Falk, K., Nøhr, H., Bendix, K. & Hagge, H. 1991. Arealanvendelsen og fuglelivet i Ballum Enge. – Rapport udarbejdet af Ornis Consult, København.

Hälterein, B. Fleet, D.M., Henneberg, R., Mennebäck, T., Rasmussen, L.M., Südbeck, P., Thorup, O. & Vogel, R. 1995. Vejledning i optælling af ynglefugle i Vadehavet.- Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group, Joint Monitoring Group for Breeding Birds in the Wadden Sea.

Kahlert, J., Hounisen, J.P., Petersen, I.K. & Bøgebjerg, E. 2003. Tøndermarskens ynglefugle 2002. Naturovervågning. Danmarks Miljøundersøgelser. - Arbejdsrapport fra DMU 182: 40 s.

Kampsax 2001. Opgørelse af permanent græsdækkede arealer i marsken for perioden 1980-99. – Rapport udarbejdet af Kampsax, Silkeborg.

Koffijberg, K., Dijksen, L., Hälterlein, B., Laursen, K., Potel, P. & Südbeck, P. 2005. Breeding birds. - In (Essing, K., Dettmann, C., Farke, H., Laursen, L., Lüerssen, G., Marencic, H. & Wiersinga, W. Eds.); Wadden Sea Quality Status Report. Wadden Sea Ecosystem no. 19: 275-286.

Laursen, K. 2005. Forekomst af yngle- og trækfugle i seks EF-fuglebeskyttelsesområder i vadehavets marsk. – Arbejdsrapport fra DMU nr. 219: 1-35.

Nehls, G. 1998. Zur Entwicklung des Naturschutzgebietes Alte-Sorge-Schleife. Abschlussbericht der Effizienzkontrolle 1993-97.- NABU. Institut für Wiesen und Feuchtgebiete. Bergenhusen,

Nielsen, K.D. 1996. Vibens Vanellus vanellus og andre vadefugles ynglesucces på kreaturgræssede arealer i Margrethe Kog. – Specialerapport, Københavns Universitet og Danmarks Miljøundersøgelser.

Rasmussen, L.M. & Thorup, O. 1998. Ynglefugle i Vadehavet, 1998. Faglig rapport fra DMU nr. 229: 1-100.

Rasmussen, L.M. & Laursen, K. 2000. Fugle i Tøndermarsken – Bestandsudvikling og landbrug. – TEMA-rapport. Danmarks Miljøundersøgelser, Miljø- og Energiministeriet.

Rasmussen, L.M. 2003. Ynglefugle i Vadehavet 2001.- Arbejdsrapport fra DMU nr. 178. Danmarks Miljøundersøgelser. Miljøministeriet.

Skov- og Naturstyrelsen 1983. EF-fuglebeskyttelsesområder. Kortlægning og foreløbig udpegning i henhold til EF-fuglebeskyttelsesdirektivet.- Fredningsstyrelsen. Miljøministeriet.

Skov- og Naturstyrelsen 1995. EF-fuglebeskyttelsesområder og Ramsarområder. Kort og områdebeskrivelser. – Skov- og Naturstyrelsen, Miljø- og Energiministeriet.

Stoltze, M. (red.) 1998. Gullisten 1997 over planter og dyr i Danmark.- Miljø- og Energiministeriet, Danmarks Miljøundersøgelser, Skov og Naturstyrelsen.

Stoltze, M. & Pihl, S. (red.) 1998. Rødliste 1997 over planter og dyr i Danmark.- Miljø- og Energiministeriet, Danmarks Miljøundersøgelser, Skov og Naturstyrelsen.

Thorup, O. 1998. Ynglefuglene på Tipperne 1928-1992. – Dansk Ornithologisk Forenings Tidskrift 92: 1-192.

Thorup. O. 2004. Status of populations and management of Dunlin Calidris alpina, Ruff Philomachus pugnax and Black-tailed Godwit Limosa limosa in Denmark.- Dansk Ornitologisk Forenings Tidskrift 98: 7-20.

Appendix 1

Number of breeding birds in SPAs (Ribe, Mandø, Fanø) 1983-2001. Species names in bold: Specific species on Annex 1 of the Birds Directive for which the SPA is appointed. Species names in italic: Species on the Annex 1, which are also listed in the description of the SPA. Species names in normal: Additional species listed in the description of the SPA. + indicate that the species was recorded. – No information. ** One pair in 1994.

SPA no. 51, Ribe	1983	1987-88	1993-94	1996	2001	Trend
Garganey	-	2-3	2	0	0	D
Shoveler	-	3-5	5-10	0	0	D
Montagu's harrier	-	0-3	1-2	-	3*	-
Marsh harrier	-	0-2	2-4	3-4	>4	**I**
Hen harrier	0	0	0	0	1	**A**
Avocet	+	150-200	300	190	163	**S**
Ruff	-	0-5	5-10	0	0	**D**
Black-tailed godwit	10	12-20	15	25	6	D
Short-eared owl	+	0	0-2	1	0	**S**
Yellow wagtail	-	10	+	+	+	-
SPA no. 52, Mandø	**1983**	**1987-89**	**1991**	**1996**	**2001**	**Trend**
Wigeon	-	0-1	-	0	0	-
Gadwall	-	0-2	-	0	0	-
Teal	-	0-1	1-2	0	0	S
Pintail	-	0-1	-	0	0	-
Shelduck	-	-	19	-	-	-
Eider duck	400	120-210	286	+	403	S
Marsh harrier	+	1-3	2	+	2-3	-
Avocet	-	7-71	14	21	81	**S**
Kentish plover	-	0-1	0	0	0	**A**
Dunlin	+	0-1	1	0	1	**S**
Redshank	-	-	136	317	161	-
Lapwing	-	-	172	166	174	-
Oystercatcher	-	-	454	1086	569	-
Ruff	-	8-16	12	0	0	**D**
Black-tailed godwit	10	21-27	30	22	68	I
Turnstone	-	-	0**	0	0	-
Gull-billed tern	-	-	1	0	0	-
Common tern	-	25-35	37	143	43	**I**
Arctic tern	-	90-370	235	87	144	**S**
Little tern	-	0-1	0	0	0	**A**
Short-eared owl	-	-	0	3	3	-
SPA no. 53, Fanø	**1983**	**1988-89**	**1993-94**	**1996**	**2001**	**Trend**
Bittern	-	3-4	3-4	5-6	7	**I**
Greylag goose	-	-	1	5-6	10	-
Teal	-	2-8	3-5	0	0	D
Shoveler	-	2-4	0-2	0	0	D
Montagu's harrier	-	2-3	0	0	0	**D**
Marsh harrier	-	3-4	3-4	3-4	9	**I**
Hen harrier	0	0	0	1	0	**A**
Avocet	10	19-38	12-38	18	9	**S**
Kentish plover	+	4-10	19-21	16	16	**I**
Dunlin	-	9	6-11	7	6	**S**
Ruff	+	0	0	0	0	**D**
Curlew	8	26-33	23-30	10	22	I
Arctic tern	-	55-90	11-28	47	9	**D**
Little tern	20-30	30-42	65-75	53	7	**D**
Stock dove	-	16-22	20-25	+	20-30	-
Short-eared owl	-	1-2	0	0	0	**D**
Bearded tit	-	0-10	10-50	+	5-10	-
Grasshopper warbler	-	6-7	3-5	0	0	D

Appendix 2

Number of breeding birds in SPA, Tønder Marsh (Magisterkogen, Ydre Koge and Margrethe Kog) during 1983-2001. Species names in bold: Specific species on Annex 1 of the Birds Directive for which the SPA is appointed. Species names in italic: Species on the Annex 1, which are also listed in the description of the SPA. Species names in normal: Additional species listed in the description of the SPA. + indicate that the species was recorded. – No information. * Figures from 2002.

SPA no. 60: Tønder Marsh						
Magisterkogen	1983	1988	1993	1996	2001	Trend
Bittern	14	4	3	3	6	**D**
White stork	1	1	1	1	0	**D**
Gadwall	1	0	2	3	7	I
Teal	1	0	1	0	0	S
Garganey	35	4	9	10	8	D
Pintail	0	0	0	1	1	I
Marsh harrier	25	11	19	18	15	**D**
Montagu's harrier	6	12	6	0	3	**D**
Spotted crake	8	5	7	2	4	**D**
Black-tailed godwit	13	8	5	3	0	D
Common tern	0	0	1	3	0	**A**
Black tern	4	3	0	3	0	**D**
Bluethroat	-	-	1-4	1	19*	-
Ydre Koge	1983	1988	1993	1996	2001	Trend
Bittern	7	4	5	1	2	**D**
Wigeon	0	0	1	0	0	A
Gadwall	0	4	8	14	18	I
Teal	0	0	1	0	0	A
Garganey	76	17	53	12	24	D
Marsh harrier	7	4	5	1	2	**D**
Montagu's harrier	4	3	1	1	0	**D**
Black-tailed godwit	202	92	75	61	82	D
Black tern	72	21	36	46	12	**D**
Margrethe Kog	1983	1988	1993	1996	2001	Trend
Wigeon	0	5	3	2	3	S
Gadwall	3	14	15	23	22	I
Teal	3	5	5	0	2	D
Garganey	19	6	5	4	5	D
Pintail	0	8	3	2	1	S
Marsh harrier	2	1	0	1	0	**D**
Montagu's harrier	2	1	0	0	0	**D**
Avocet	108	423	482	268	143	**I**
Kentish plover	34	16	0	1	2	**D**
Dunlin	1	2	0	0	0	**D**
Black-tailed godwit	23	32	45	31	42	I
Common tern	0	105	124	68	10	**S**
Arctic tern	38	7	34	54	0	**D**
Little tern	9	3	0	0	0	**D**

* in 2000

Appendix 3

Number of breeding birds in SPAs (Rømø, Ballum) during 1983-2001. Species names in bold: Specific species on Annex 1 of the Birds Directive for which the SPA is appointed. Species names in italic: Species on the Annex 1, which are also listed in the description of the SPA. Species names in normal: Additional species listed in the description of the SPA. + indicate that the species was recorded. – No information. `Figures from 1994.

SPA no. 65, Rømø	1983	1988	1991	1996	2001	Trend
Bittern	1	5-9	2-3`	+	+	-
Gadwall	-	4-5	-	0	0	-
Teal	-	9-11	-	0	0	-
Pintail	-	0-2	-	2	0	-
Garganey	-	3	-	0	0	-
Shoveler	-	10-12	-	0	0	-
Montagu's harrier	+	6-7	9`	+	1	-
Hen harrier	-	-	1`	2	0	-
March harrier	+	7	-	+	>5	-
Spotted crake	-	0-1	-	0	0	-
Avocet	30-50	53	10-15`	67	47	**S**
Dunlin	20-25	23	22	18	12	**D**
Ruff	40-50	15-19	12	0	3	**D**
Kentish plover	25	20-22	10	38	68	**I**
Curlew	25	34	36	26	20	S
Black-tailed godwit	80	79	83	62	73	S
Common tern	40-50	25	50	0	2	**D**
Arctic tern	170	300	109	630	281	**I**
Sandwich tern	+	0	0	0	0	**D**
Gul-billed tern	-	-	2-3`	8	1	-
Little tern	8-12	18	10	136	162	**I**
Short-eared owl	1-2	1	0	5	0	**D**
Grashopper warbler	-	11-13	-	-	-	-
SPA no.67, Ballum	1983	1989	1990	1996	2001	Trend
Garganey	-	1-3	-	0	0	-
Teal	-	5-8	-	0	0	-
Shoveler	-	1-3	-	0	0	-
March harrier	-	-	2`	+	>15	-
Montagu's harrier	-	-	4`	-	15	-
Lapwing	-	550	299	602	409	S
Black-tailed godwit	+	19	15	42	12	D
Redshank	-	14	-	207	160	-
Ruff	min. 10	0	0	0	0	**D**
Short-eared owl	+	0	-	0	0	-

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